Volume 24 OCTOBER, 1940 Number 10

BULLETIN
of the
American Association *of* Petroleum Geologists

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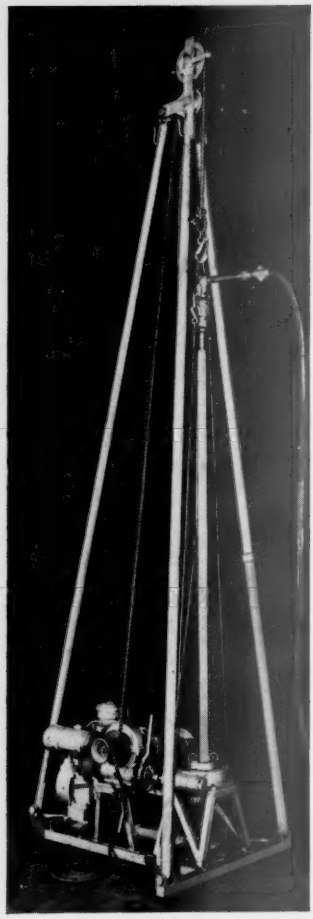

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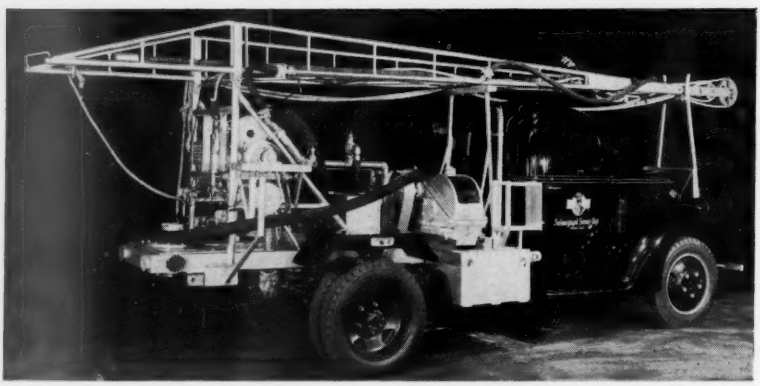

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of the

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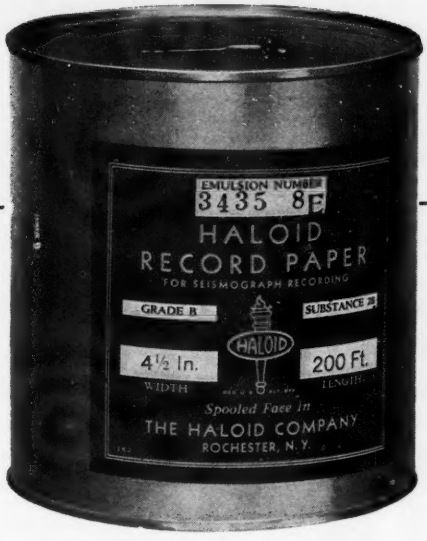

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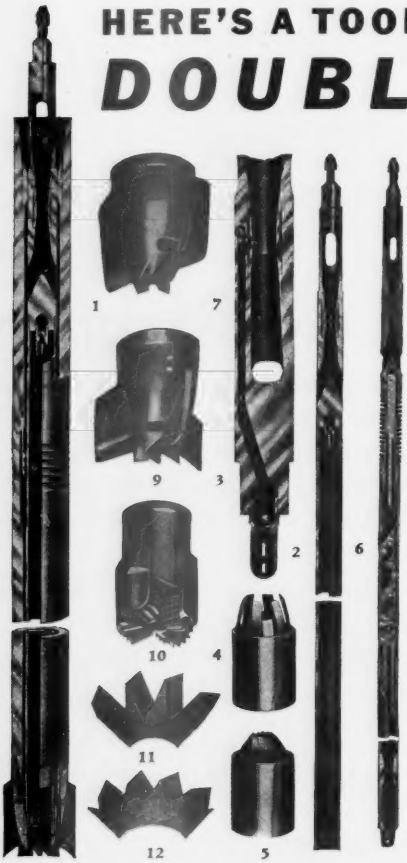

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By Frank J. Gardner

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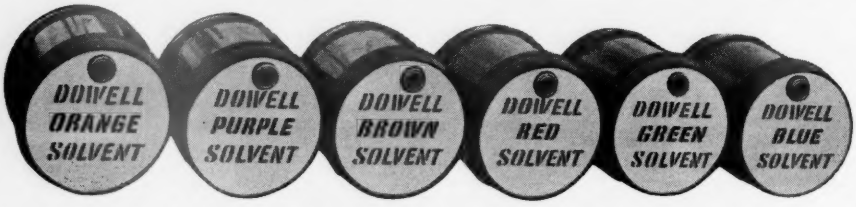

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TWENTY YEARS OF PETROLEUM GEOLOGY IN CALIFORNIA[1]

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ABSTRACT

Four new oil fields to which 45,500,000 barrels of oil reserves have been assigned were discovered in California during 1939; extensions or revisions of existing fields added 257 million barrels of estimated ultimate production; total 302,500,000 barrels of new oil. The 1939 production in the state was 224,354,048 barrels. Estimated reserves were increased by 78,146,000 barrels of oil for a total of 3,178,500,000 barrels as of January 1, 1940.

Of more interest to petroleum geologists than merely 1939 statistical data might be a summary of geological endeavors and results in California during the past 20 years and a prophecy for the future. Geological employment and geophysical activity from 1920 to 1939 inclusive are summarized and are correlated with results: namely, new fields discovered, producing wells completed, reserves proved, dry holes drilled, *et cetera*. Progress of geological thought and changing exploration methods are traced and new developments made possible by deep drilling are outlined. It is concluded that more geological man-years than in the past will be necessary to discover and develop a unit quantity of California's new future oil and gas production.

INTRODUCTION

The purpose of this paper is to sketch geological endeavors in California during the past 20 years and to compare these activities with results. Trend of geological employment and, more recently, geophysical activity should supply an index of endeavors. Indicative of results are new fields discovered and areal and vertical extensions of old fields, average depth of discoveries, number of abandoned wildcat wells together with average and maximum depths, current wildcat activity, producing wells completed, production statistics and reserve estimates. Fresh geological thought and new geological and geophysical methods have contributed to the rapid changes of the past two decades. A review of the past should be helpful in forecasting the future and some useful lessons may be learned from such a review.

[1] Read before the Association at Chicago, April 12, 1940. Manuscript received, April 11, 1940.

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ACKNOWLEDGMENTS

The writer has drawn freely on literature and statistics relating to California oil production. Particular use has been made of data assembled by Hoots[3] and of publications of the Division of Oil and Gas.[4]

Gratitude for useful information is expressed to Dwight H. Thornburgh of the General Petroleum Corporation, E. R. Atwill of the Union Oil Company, Martin Van Couvering, consultant, F. E. Minshall of the Continental Oil Company, and to State oil and gas supervisor R. D. Bush. Particular thanks are due the chief geologists of various oil companies for data of geological employment. Harold K. Armstrong, consultant, and R. E. Collom, Glenn H. Bowes, and E. H. Vallat of the Continental Oil Company made helpful suggestions.

EARLY HISTORY

Before entering upon a review of geological activities and results during the period from 1920 to 1939 inclusive, it would be best to lay a foundation upon which to start. The first oil well in California was completed in 1875 in Pico Canyon which is 32 miles northwest of Los Angeles. By 1903 approximately 37 oil fields or groups of small fields, 10 of which are considered important, were discovered by drilling. These discoveries were largely the results of stepping out from oil seeps. The discovery rate was 1.3 oil fields per year. All sorts of reservoir types as we now know them were found and developed at shallow depths almost entirely without professional geological aid. Results indicate that the early explorers for California's oil were "pretty good geologists" for their time; they pointed the way for subsequent endeavor. During this period, 65,800,000 barrels of oil was produced which was approximately 5.2 per cent of the total production of the United States to the year 1903 inclusive, and a sizable reserve of more than one billion barrels of oil had been proved.

The period from 1904 to 1907 inclusive was represented by lean years as no new oil fields were found. This can be attributed to the following factors: (1) lack of demand, (2) depth limitation because of costs and hazards, (3) all obvious possibilities as indicated by surface evidence of oil had been drilled, and (4) geology as we now know it had not yet become a practice.

Between the years 1905 and 1910 geologists became important factors in the search for new oil fields. They were rewarded by a series of discoveries beginning in the year 1908. From 1908 to 1919 inclusive,

[3] Harold W. Hoots, "Additions to Oil Reserves in California during 1938," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 6 (June, 1939), pp. 932–48.

[4] *Summaries of Operations, California Oil Fields*, Vols. 11–23, monthly chapters of the annual reports of the State oil and gas supervisors.

16 oil fields were discovered; ten of them were of major importance. This was a discovery rate of 1.3 fields per year for 12 years which was the same as for the previous period but the fields were larger and 2,400 million barrels of ultimate production was added as compared with 1,100 million barrels for the 28 years prior to 1904. Deeper drilling made possible by heavier cable-tool equipment, combination tools, and in 1910 the rotary, shared equal honors with geology for these achievements.

The year 1920 began with past production of 1,245,728,154 barrels of oil, being 25 per cent of the total for the United States, and approximately 2,218 million of estimated reserves, making an estimated ultimate of 3,464 million barrels of oil from 53 oil fields of assorted sizes, 20 of which might be ranked as of worth-while importance. The geologist had passed beyond the stage of being a necessary evil and a period of rapid advancement in all scientific and mechanical methods of exploring for oil was beginning.

ACTIVITY

All oil and gas discoveries of any importance in Califorina during the past 20 years have been made by companies maintaining competent geological and/or geophysical staffs. An analysis of the degree of employment of geologists and geophysical crews of such companies in this 20-year period should supply a good index of activities to compare with results.

GEOLOGICAL ACTIVITY

At the request of the writer, 17 oil companies contributed data showing the average number of geologists employed by them, by years for the period 1920 to 1939 inclusive, in exploration geology or work relating thereto in California. A summation of this information appears in graphic form in Figure 1. Exploration employment follows closely the boom and depression periods of the past 20 years. During the "twenties" new oil-company entrants into California built up sizable geological staffs, and some old companies, that had not previously engaged geologists in exploration, employed them for this purpose; these are called "new companies." The exploration-employment graph has been broken down into graphs for "old companies" and "new companies." It is interesting to note the more stable appearance of the "new companies" graph as compared with that of the "old companies." Also in Figure 1, to show relation of price to employment, are plotted data of average price of California oil by years as compiled by the California State mineralogist. The effect of price fluctuations on geological activity is quite evident, but in the late "thirties" activity

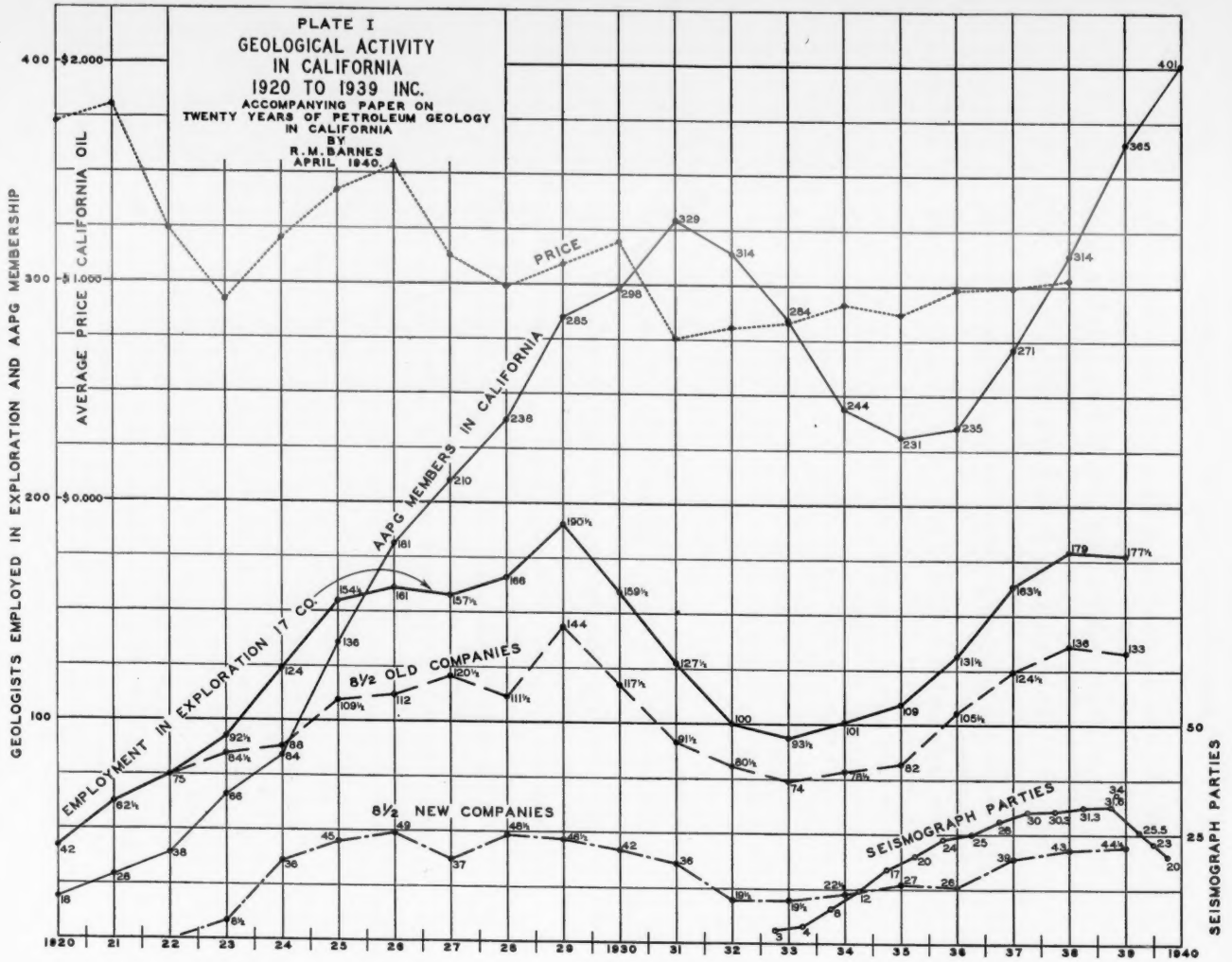
PLATE I
GEOLOGICAL ACTIVITY
IN CALIFORNIA
1920 TO 1939 INC.
ACCOMPANYING PAPER ON
TWENTY YEARS OF PETROLEUM GEOLOGY
IN CALIFORNIA
BY
R. M. BARNES
APRIL 1940.
GEOLOGISTS EMPLOYED IN EXPLORATION AND AAPG MEMBERSHIP
AVERAGE PRICE CALIFORNIA OIL
SEISMOGRAPH PARTIES
PRICE
AAPG MEMBERS IN CALIFORNIA
EMPLOYMENT IN EXPLORATION 17 CO.
8½ OLD COMPANIES
8½ NEW COMPANIES
SEISMOGRAPH PARTIES
400
300
200
100
$2.000
$1.000
$0.000
50
25
1920
21
22
23
24
25
26
27
28
29
1930
31
32
33
34
35
36
37
38
39
1940

FIG. 1

increased more rapidly than prices. The number of members in The American Association of Petroleum Geologists with residence in California is also plotted in this figure. After 1926 the difference between the membership graph and the exploration-employment graph can be accounted for by many additional geologists engaged in development or exploitation geology, consultants, and geologists working outside of California but maintaining official residence in the state.

During the "twenties," exploration geology, which reached a peak in 1929, consisted of the conventional type supplemented by physiographic and trend studies which played an important rôle in the Los Angeles Basin discoveries and to a lesser extent in the San Joaquin Valley. In the Los Angeles Basin much rewarded effort was given toward reconstructing topography and studying of soil maps. Some unrewarded work was done throughout the state on data which could be collected from and in many shallow wells drilled for water. Work with Foraminifera which was commenced in 1923 began to yield reliable results by the end of this period.

Of course it can be seen and understood that geological activity was on the decline and at a low ebb during the depression years of the early "thirties." By that time most of the obvious and readily mappable structures had been tested. During this lull, considerable regional geological reconnaissance was done in California outside of the provinces in which commercial oil and gas had already been found.

From the time of the employment low in 1933 to a 1938–1939 peak which approached that of 1929, geological activities took on new aspects. More detailed surface and subsurface studies became possible because of improved tools. The geologist was exposed to results of the reflection seismograph which in turn broadened his outlook and field of activity. Research which showed that many of the earlier and current discoveries were related to stratigraphic and lithologic changes intensified the amount of detailed surface and subsurface work that was done on stratigraphy. More recently the problem of finding oil under California's many important thrust faults is attracting increasing attention.

The use of Foraminifera for surface and subsurface correlations became common in the "thirties," but Foraminifera are now being supplanted by electrical logs within proved areas. During this period the increasing value of electrical logs for correlation purposes and of both electrical logs and core analyses as an aid to discovery have played important parts in the upward trend of geological endeavors.

To the geologist engaged in evaluation, core analyses and bottomhole data are making possible a volumetric method of calculating re-

FIG. 1

serves. This method is in the process of replacing decline curves which have been of limited value since proration was begun in 1929.

As an example of the influence of improved drilling equipment and technique on oil exploration and development, a well 11,000 feet deep can now be completed at no greater cost than was spent for a 5,500-foot well in 1926. Drilling speeds have doubled and tripled.

It may be axiomatic to state that, as time passes, more geological manpower will be necessary in finding a unit quantity of new oil unless the oil executive's dream (or geologist's nightmare) of an infallible direct means of locating oil comes true. New methods and tools and continually increasing data of wells drilled have a tendency to increase geological personnel. Adverse to this trend are local disturbances in the oil business such as overproduction, price wars, business depressions and world unrest over which the geologist has no direct control. Prophecy as to future trend of geological employment and endeavor will be presented on another page in this paper after activities have been correlated with results.

GEOPHYSICAL ACTIVITY

Considerable refraction-seismograph work was done in California during the middle and late "twenties" without providing any data that can be directly related to subsequent discoveries. The same can be said for torsion-balance and magnetometer surveys which were made during this period and have continued at intervals to the present time. The chief value of the magnetometer as an exploration tool may be attained as a result of extremely detailed work in local areas. In 1937 some gravity-meter parties entered California and one party is still active. This instrument furnishes a rapid means (as compared with the torsion balance) of measuring gravity changes in a large area; these changes in California may or may not be related to structures which might contain oil. Some electrical resistivity work has been done in California with interesting results at shallow depths. The finding of one small oil field was aided by such a survey.

The first reflection-seismograph crews entered California in 1931. Early work was done by correlation shooting but soon a method of dip shooting was developed which rapidly supplanted the former method. More recently a refined combination of correlation and dip shooting is proving effective.

Figure 1 contains a graphic representation of the amount of reflection-seismograph work which has been done from 1933 to early 1940. From 3 crews in 1933 the number of parties increased to 34 in April, 1939, and then began a rapid decline to 20 crews in March, 1940. The

first geophysical gas-field discoveries in 1934 and the first geophysical oil-field discoveries in 1936 were responsible for the upward trend of seismograph activity. The recent decline may be explained by many factors. Most of the shootable areas of the state in which there is current interest in oil and gas possibilities have been covered in reconnaissance fashion. Much extreme detail work has been done in the vicinity of recent seismograph discoveries. The work which is now being done is for more detail in the vicinity of proved fields and a tightening of reconnaissance in areas already covered. Some apparently favorable seismograph structures have been drilled and proved nonproductive because of lack of proper reservoir conditions; in others tested and found dry, velocity changes wiped out the indicated structure and, in other failures, the stratigraphic conditions or faults considered essential to the trapping of oil were not confirmed by the drill. Apparently reflection-seismograph work is "taking a breather" in California. It is probable that the downward trend will soon flatten out because most companies will continue this type of exploration. However, discovery of lower productive zones and/or new regions of oil and gas possibilities within the topographic basins would no doubt cause another rapid increase in seismograph exploration.

Velocities have been determined by "shooting" approximately 60 wells in California. A group of experts to study well velocities was organized and this group has been responsible for obtaining data from 42 wells as of March 15, 1940. Such information is proving of great value for correlating and evaluating results of seismograph work.

Soil-analysis investigations (begun in 1938) and a little recent geochemical well logging do not yet justify consideration separately from geophysical activity. Soil-analysis results in the vicinity of some oil fields have shown the expected relationship; but in the vicinity of other fields this has not been true. Although considerable work in soil analysis of both reconnaissance and detailed nature has been done, it can not yet be said to have aided in discovery of a new field. Geochemical well logging in California is too much in its infancy to justify comment at this time.

RESULTS

Various types of data relating to oil exploration and development in California are shown graphically in Figures 2 and 3, for the purpose of indicating results of geological endeavors during the period from 1920 to 1939 inclusive. The graphs of exploration employment and number of seismograph parties of Figure 1 are also shown in Figure 2 and Figure 3 as an aid to comparison with results.

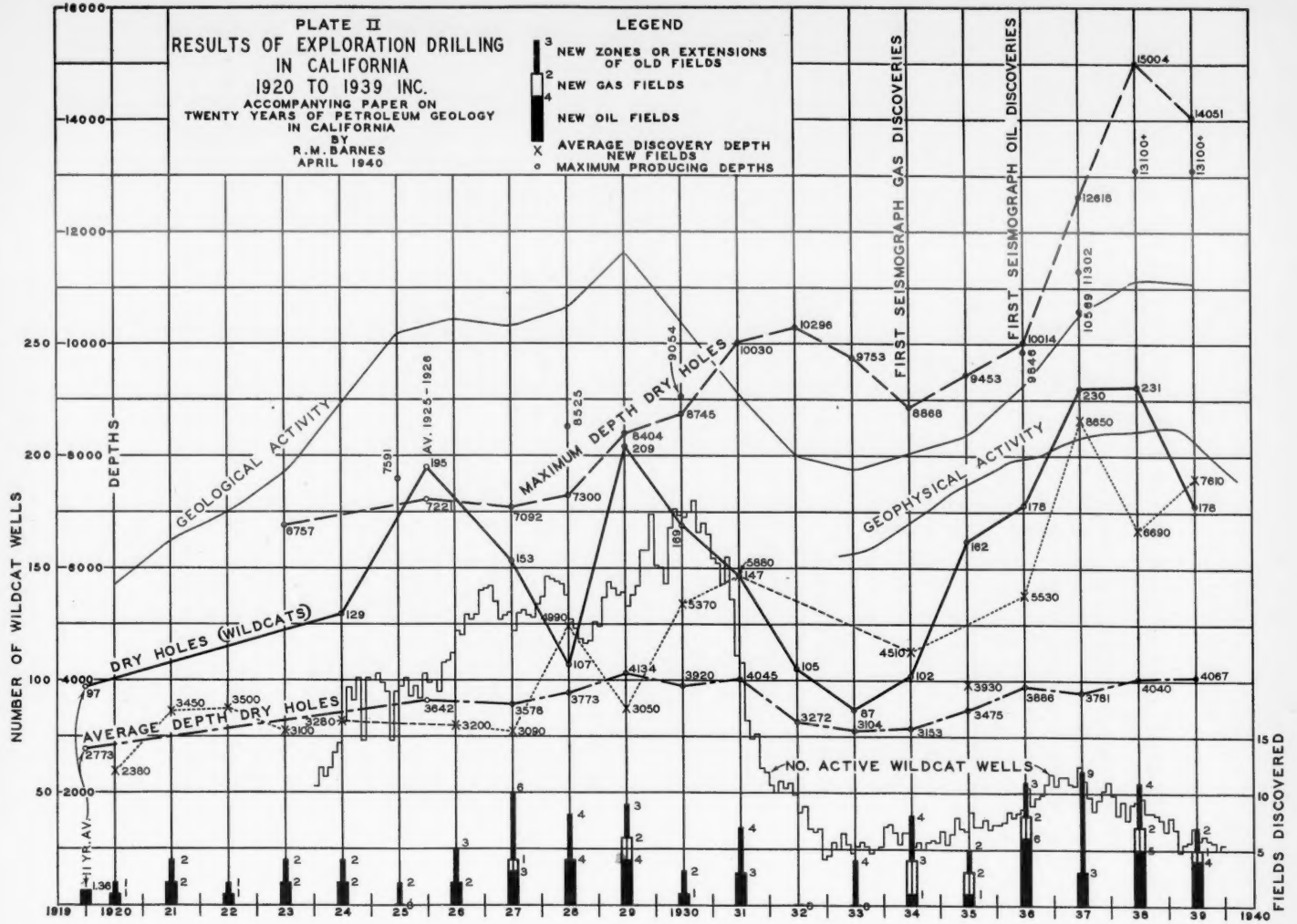
PLATE II
RESULTS OF EXPLORATION DRILLING IN CALIFORNIA
1920 TO 1939 INC.
ACCOMPANYING PAPER ON TWENTY YEARS OF PETROLEUM GEOLOGY IN CALIFORNIA
BY R.M. BARNES
APRIL 1940
LEGEND
NEW ZONES OR EXTENSIONS OF OLD FIELDS
NEW GAS FIELDS
NEW OIL FIELDS
AVERAGE DISCOVERY DEPTH NEW FIELDS
MAXIMUM PRODUCING DEPTHS
FIRST SEISMOGRAPH GAS DISCOVERIES
FIRST SEISMOGRAPH OIL DISCOVERIES
GEOLOGICAL ACTIVITY
GEOPHYSICAL ACTIVITY
MAXIMUM DEPTH DRY HOLES
DRY HOLES (WILDCATS)
AVERAGE DEPTH DRY HOLES
NO. ACTIVE WILDCAT WELLS
NUMBER OF WILDCAT WELLS
DEPTHS
FIELDS DISCOVERED
11 YR. AV.
AV. 1925-1926
16000
14000
12000
10000
8000
6000
4000
2000
250
200
150
100
50
15
10
5
1919
1920
21
22
23
24
25
26
27
28
29
1930
31
32
33
34
35
36
37
38
39
1940

FIG. 2

FIG. 2

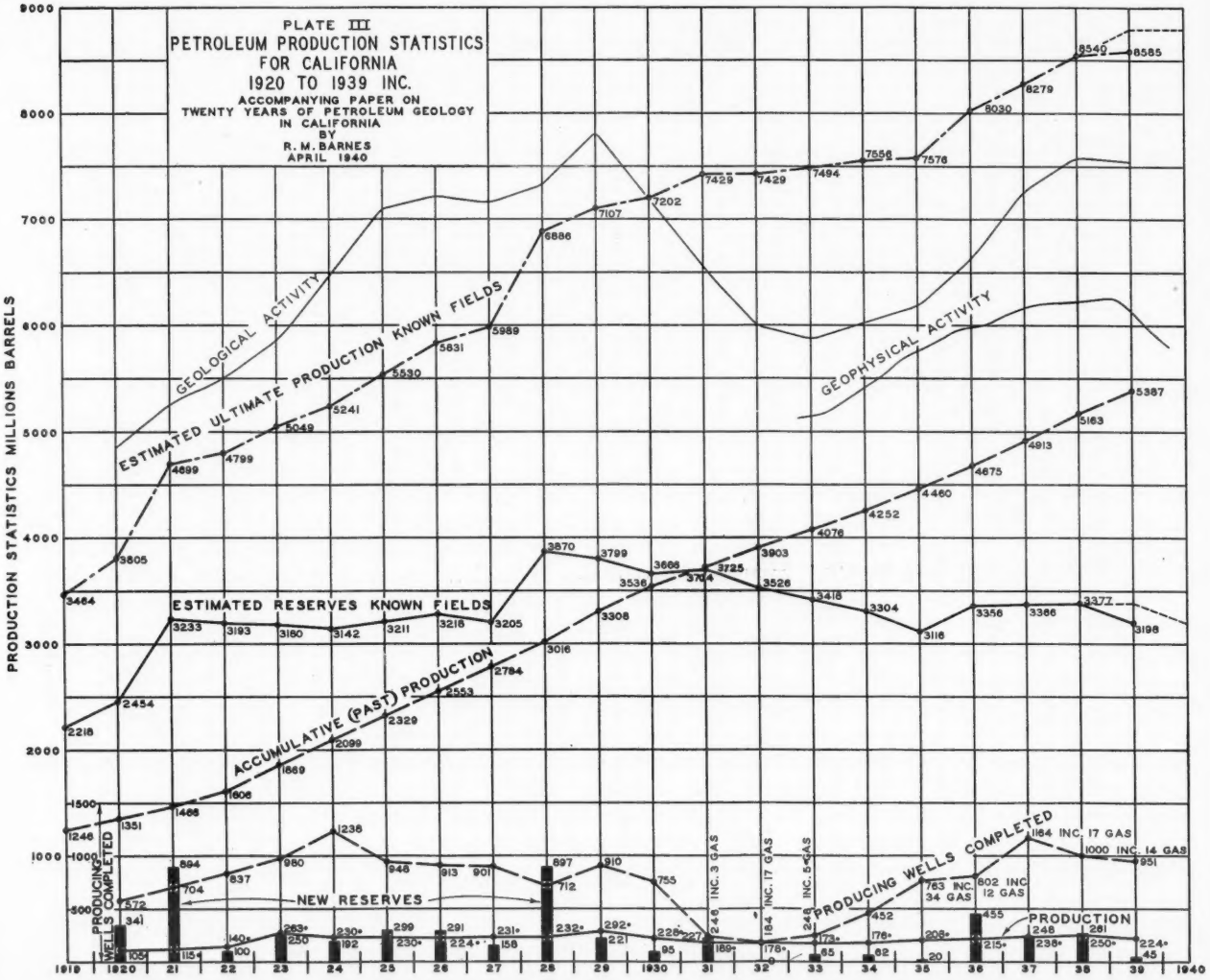
PLATE III
PETROLEUM PRODUCTION STATISTICS
FOR CALIFORNIA
1920 TO 1939 INC.
ACCOMPANYING PAPER ON
TWENTY YEARS OF PETROLEUM GEOLOGY
IN CALIFORNIA
BY
R. M. BARNES
APRIL 1940
PRODUCTION STATISTICS MILLIONS BARRELS
GEOLOGICAL ACTIVITY
GEOPHYSICAL ACTIVITY
ESTIMATED ULTIMATE PRODUCTION KNOWN FIELDS
ESTIMATED RESERVES KNOWN FIELDS
ACCUMULATIVE (PAST) PRODUCTION
NEW RESERVES
PRODUCING WELLS COMPLETED
PRODUCTION
1000 INC. 14 GAS
1164 INC. 17 GAS
763 INC. 34 GAS
602 INC. 12 GAS
246 INC. 3 GAS
184 INC. 17 GAS
245 INC. 5 GAS

FIG. 3

RESULTS OF DRILLING EXPLORATION

A great variety of information can be used to indicate results of exploration activity. The data selected for this analysis are outlined and discussed in the following paragraphs.

In the selection of new fields to be plotted for the purpose of showing results of exploration, inconsequential discoveries have not been included. Both oil and gas discoveries are shown by years in columnar fashion in Figure 2. Almost every year, deeper zones are found underlying already proved fields, and areal extensions of fields are made because of fault or stratigraphic control of accumulation of oil in off-structure positions. This situation has the same effect on reserves as the discovery of new fields. It is in part due to geological effort and partly the result of normal development. The writer has had the temerity to classify such additions as discoveries, and their number is also shown yearly by a column of lesser width in Figure 2. The average depth of wells making discovery of new fields has also been plotted in Figure 2 for comparison with other data.

The State oil and gas supervisor[5] prepares a statement of the number of wildcat wells abandoned each year together with average depth. Such wells include only those drilled to discover new fields or extensions of producing fields. These data are plotted in Figure 2 together with maximum depths of wildcat wells and a few points showing maximum depth of producing wells with relation to wildcat depths. Current wildcat activity as prepared by Martin Van Couvering from A. P. I. statistics is also shown in this figure.

As indexed by the exploration-employment graph and the seismograph-parties graph, a startling comparison may be noted between geological activity and the configuration of all graphs shown in Figure 2. With increasing geological activity, discoveries increase, more dry holes are drilled, depths become greater and current wildcat wells trend upward. With decreasing geological endeavor, the converse is true. Some wag might say that the cure for dry holes is to eliminate the geologist and the geophysicist, but if this were done practically no new fields would be discovered. The four discoveries made in 1930 and 1931 after the activity peak are largely the result of geological work done before those years. The two oil fields brought in during 1934 and 1935 are of minor importance.

The seismograph made its first gas-field discoveries in California during 1934 and its first oil-field discoveries in 1936. In the latter year 2 of the new oil fields are solely attributable to seismograph work and 4 are credited to geological effort. Much geological study has always

[5] *Op. cit.*

been necessary in connection with seismograph work in California and it would be unfair to geologists to give the seismograph entire credit for the subsequent so-called geophysical discoveries; nevertheless seismograph results pointed the way. From 1934 on, division of credit for new fields might be made as follows.

Year	*Oil Discovery*			*Gas Discovery*		
	Geology	*Combination*	*Seismograph*	*Geology*	*Combination*	*Seismograph*
1934	1				1	2
1935	1					2
1936	3	1	2			2
1937	1	1	1			
1938	3	1	1	1	1	
1939	1	1	2	1		
	10	4	6	2	2	6
	20 total			10 total		

From 1920 to 1939 inclusive 45 oil fields and 13 gas fields were discovered in California. Of the oil fields, 31 are of major importance. This makes a total of approximately 98 oil fields in California, 51 of which are important. During this 20-year period approximately 60 new zones in, and extensions of, already proved fields were also added and this can be considered in effect the equivalent of new oil-field discoveries. This discovery rate was 2.25 new oil fields per year, 0.65 new gas field per year and 3 extensions or new zones per year. Compare these figures with the rate of 1.3 fields per year already given for the two periods prior to 1920.

Let us divide this 20-year period into two parts: B. D. (before depression) and A. D. (after depression), or we might say B. S. (before seismograph) and A. S. (after seismograph). From 1920 to 1931 inclusive, 25 oil fields and 3 gas fields were found at the rate of 2.1 minus oil fields and 2.3 plus oil fields and gas fields per year. This period represents B. D. or B. S. During the 6-year period from 1934 to 1939 inclusive with geophysics entering into the picture, 20 oil fields and 10 gas fields were discovered at the rates of 3.4 plus oil fields per year and 5 oil fields and gas fields per year.

Some other interesting calculations can be made from the data in Figure 1 and Figure 2. During the 12-year period from 1920 to 1931 inclusive, the discovery of 28 oil fields and gas fields consumed at least 1,512 geologist years or an average of 54 years of a geologist's life per field. From 1932 to 1939 inclusive, 30 oil fields and gas fields were found as the result of more than 1,060 geologist years and more than 130 seismograph-party years. Allocating credit for discoveries in ac-

cordance with division in this table, and dividing the combination discoveries equally, geologists were responsible for finding 15 oil fields and gas fields at the rate of more than 70 geologist years per field and seismograph parties discovered 15 oil fields and gas fields at an average of more than 9 party years per field. If the average cost of a geologist is $500 per month and the average cost of operating a seismograph crew is $8,000 per month, the ratio of cost of discovery is approximately 1 to 2 in favor of the geologist. Of course this comparison is not entirely logical because the geologist can not do what the seismograph can do (one critic of this paper adds "and *vice versa*"). Converting geologist years into geological cost, each geological field discovery cost $324,000 between 1920 and 1931, and $420,000 from 1932 to 1939 inclusive whereas geophysical cost of seismograph discoveries averaged $864,000 per field.

Let us now investigate the dry-hole record in California, bearing in mind that some of the abandoned wildcats making up the data in Figure 2 were not drilled to discover new fields. More than 3,000 dry holes were drilled during the time of discovery of 58 oil fields and gas fields in the 20-year period from 1920 to 1939 inclusive. This is an average of 52 dry holes per new field. For the reason given this figure can be lowered somewhat. The average for the recent 6-year discovery period was 36 dry holes per new oil field and gas field. Another interesting figure that can be deduced from data in Figure 2 is that an average of 185,000 feet of dry hole has been drilled per new field discovered during the 20-year period under consideration. Assuming a total cost of $40 per foot, including all exploration costs, the average cost of finding a new field is $7,400,000. Although the price of discovery "comes high" in California, the reward has been attractive. From 1920 to 1939 inclusive, estimated ultimate production was increased more than 5 billion barrels principally by the 45 new oil discoveries. This is an average reward of 110 million barrels of oil per field.

The following are some other pertinent points regarding data in Figure 2.

1. The exploration-employment graph and the dry-holes and wildcatting curves sagged in the late "twenties" before reaching the 1929 peaks. This is attributable to a period of overproduction, the depressing effect of which was soon overcome by the prevalent boom spirit.

2. Much of the increase in wildcatting after the low in 1933, as indicated by the dry-holes curve, can be credited to seismograph work. The flattening and decline in the late "thirties" was caused more by decline in exploration based on seismograph work than by leveling-off of geological activity.

3. The average depth of dry holes has changed slowly but maximum drilling depth has increased rapidly, especially in the late "thirties," when deep exploration was influenced by results of seismograph work in the valley floors. Both of these curves show the influence of good and poor times. The relation of average discovery depths of new fields to average depths of dry holes is interesting in that from 1930 to 1939 (inclusive) discovery depths average deeper than dry holes and especially so in the late "thirties." It might appear that the average wildcat well was not drilled deep enough to strike production but part of this situation was caused by many wildcat wells drilled in known shallow territory without reward.

4. The first well in California deeper than 10,000 feet was drilled in 1931, and in 1938 a well was drilled to 15,004 feet. The first production of oil from a depth greater than 10,000 feet occurred in 1937. Near the graph showing maximum depth of dry holes are circles representing maximum depths of production; depths of producing wells were greater than the maximum depths of abandoned wildcats until 1930. In 1937 and 1938 maximum producing depths and maximum abandoned wildcat depths increased rapidly with the latter outstripping the former. Maximum depth of oil production in California is at present 13,100 plus feet.

5. The graph showing the number of wildcat wells active each month reached a peak in 1930 and then sagged rapidly into the depression period. The subsequent peak in 1937 is not marked and is only one-third of the 1930 peak. One of the reasons for this is the rapidity with which wildcat wells are now drilled and abandoned as compared with the period during "twenties" and early "thirties." With equal drilling times the 1937 peak would have been much higher.

PRODUCTION DATA AND RESERVES

An assignment of 45,500,000 barrels of new oil reserves has been given to the four oil fields discovered in California during 1939. Extensions or revisions of existing fields conservatively added 257 million barrels of new oil. The 1939 oil production in the state was 224,354,048 barrels. Estimated reserves were therefore increased during 1939, according to conservative estimates, by 78,146,000 barrels to a total of 3,198,500,000 barrels of oil as of January 1, 1940. This increase will not coincide with the reserve graph in Figure 3 for reasons which will be explained later.

Exploration activity in the 20-year period under consideration can probably be correlated with production and reserves. Figure 3 has been prepared for this purpose. It shows graphically by years the num-

ber of producing wells completed, oil production, reserves developed and customary curves of past, estimated future, and estimated ultimate oil production.

The graph showing producing wells completed reaches an all-time peak of 1,238 wells in 1924. This was the result of intensive development in the prolific Los Angeles Basin oil fields discovered during the early "twenties." Influenced by overproduction, there was a sag into a secondary low in 1928 and then production reached a lesser peak in 1929 caused by a "boom spirit" in spite of overproduction. The depression low witnessed only 184 well completions in 1932. Thence the graph goes up rapidly to another peak of 1,164 completions in 1937. It can be seen that this graph conforms closely with activities and with the various results shown in Figure 2. A graph of well potentials would be meaningless because of varying methods of determination.

For the sake of consistency, annual production and new reserves have been plotted in Figure 3 to the same scale as the other production statistics. Consequently they do not show outstanding relief. A dot has been placed after each production figure to prevent confusion with the new reserve figure. California reached an all-time production peak of 292,036,911 barrels of oil in 1929. An earlier peak of 263,728,895 barrels of oil was attained in 1923 and a recent high of 249,749,246 barrels of oil appears in 1938. The production graph shows fair agreement with well completions and also is quite similar to the activities graphs and to the results graphs shown in Figure 2.

In plotting the new-reserves graph shown in columnar fashion in Figure 3, use has been made of the data and scheme given by Hoots.[6] That is, the new-reserve estimates for any one year have been allotted to the year of discovery of a field prior to 1935 and to the year of discovery of a field or zone from 1935 forward. Thus, according to this scheme, an estimate of reserves made at the end of 1940 may give a corrected assignment of 200 million barrels of oil to 1939 rather than the 45,500,000 barrels which has been arbitrarily assigned for the four new fields discovered in that year and may also increase new reserves and total reserves for former years. The dashed lines at the end of the reserves and ultimate-production graphs show anticipated effect of the application of this scheme in 1940 for the years 1939 and 1940. The reason for following this scheme is to relate reserves to the time of discovery, rather than to the time of proof and development, as an index of the results of exploration instead of development. The 1921 new-reserves peak is caused by allotting back reserves later proved at the Santa Fe Springs,

[6] *Op. cit.*

Long Beach, and Huntington Beach oil fields, and the 1928 peak reflects discovery of the Kettleman North Dome oil field. The lesser 1936 high results principally from the Ten Section, Santa Maria Valley, and Wilmington discoveries in that year. According to Hoots' scheme the final height of these columns can not be plotted until the last barrel of oil assignable to each year can be estimated. It will be noted that even now the trend of new reserves follows the shape of the activities graphs and the results graphs shown in Figure 2.

Little need be said regarding the accumulative production graph except to note that it follows an easy curve trending upward at a nearly uniform rate and controlled by the same economic forces as those which influenced exploration activity and results. At the end of 1939 California had produced 5,387,245,708 barrels of oil which was 24 per cent of total United States past production.

The estimated-reserves graph is also influenced by the scheme of throwing new reserves back into the year of discovery of the field or zone. This accounts for the sudden increases in 1921, 1928, and 1936. An estimate made for 1940 will look something like the dashed line at the end of the graph. By making proper allowance for these irregularities, the remarkably horizontal trend of reserves in spite of increasing demand is very noteworthy. The downward trend in the early "thirties" is the direct result of decline in exploration during the depression years. Using the estimated-reserves figure of this paper, California's reserves are 17.6 per cent of the total estimated for the United States. If the more optimistic A. P. I. estimate of California's reserves of 3,532,342,000 barrels of oil is used, this proportion is raised to 19.1 per cent.

Aside from the sudden increases already cited as caused by method of computing, and except for the flattening during the depression years, the ultimate-production graph shows an upward trend at a nearly uniform rate. Estimated ultimate production of oil in California was increased 5,121 million barrels during the 20-year period under discussion to a total of 8,585 million barrels of oil as of January 1, 1940. During this twenty-year period, $1\frac{1}{2}$ times as much oil was found in California as was found in the 45 years prior thereto. On a time basis, ultimate production of oil was proved at a $3\frac{1}{3}$ times greater rate during the last 2 decades than during the 45 years of prior development.

CONCLUSIONS

Many inferences can be drawn from a study of the data presented in the three figures accompanying this paper. Some of these inferences should be applicable to oil-producing localities other than California.

It is hoped this paper will stimulate a correlation of exploration activities and results for other oil-producing provinces that then might be combined into a general picture for the United States. Different readers may arrive at various answers but the writer believes that the outstanding conclusions of this study can be covered in the following brief statements.

Certainly, economics has controlled exploration and results in California. There has been a direct relationship between geological activity, drilling exploration, and discoveries during the past 20 years. Reserves increased during the boom years of the "twenties" and declined with diminishing geological activity and exploratory drilling in the depression years of the "thirties." This depression will have the lasting effect of delaying the finding of California's ultimate production. The increase in exploration and discoveries during the late "thirties" served merely to maintain the reserve position.

Oil reserves are the "life blood" of any successful oil company. At the present stage of the oil industry in California, reserves must not be allowed to decline. If reserves are to be maintained in the existing horizontal trend for as long as possible, exploration must continue in an upward trend and without the fluctuations of the past 2 decades.

More exploration and, consequently, more geological manpower will be required to find a unit quantity of new California oil in the future than has been necessary in the past. This is because all of the obvious geological and geophysical prospects have already been tested. The last oil field will be the most difficult and most expensive to find.

Fluctuations of exploration activities within the oil industry are inefficient because of the loss of experienced men who may never return to the industry and because of the cost and time consumed in rebuilding an exploration organization.

Geological activity in California should increase. The unfortunate variations, which are controlled by economics, should be kept at a minimum in both time and intensity. Is the exploration-employment graph about to decline as it did after 1929 or is the current leveling of this graph merely one of those minor fluctuations which occurred during the period from 1925 to 1927? The writer believes that if oil-company executives will accept a logical view of the need for continued exploration, an upward trend of geological employment with minor fluctuations will be the answer.

From now on, the seismograph will have its "downs" and "ups" in California as requirements call for its use by geologists but the trend should be nearly horizontal, unless new regions or deeper zones of oil production are discovered in the basins.

The reason for greater stability of geological employment by the oil companies that started exploration in California during the "twenties," as compared with those already in the field, is probably a greater need for reserves by the newer companies. The older companies were better intrenched. Another explanation may be fresher and more intensive geological thought on the part of new entrants.

Wildcat wells will probably be drilled to greater depths in search of oil in lower Tertiary sands and even into Cretaceous sands at low positions in California's structural basins. Whether or not deeper production of oil can be developed, will depend on the reservoir characteristics of such sediments. Recent discoveries of Eocene oil have been close to shore lines at relatively shallow depths. Will these sands have reservoir characteristics favorable to production of oil at great depths in the sedimentary and structural basins? On these conditions as well as the existence of suitable traps will depend the maximum depths from which oil will eventually be produced in California.

Finally, continued exploration is essential as a means of maintaining California's reserve position as long as possible. Whether or not exploration can be actively carried on during the near future will depend on the outcome in a battle of foresight against current economic demands. For the benefit of the oil industry in California, it is hoped that foresight will prevail.

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EOCENE YOKUT SANDSTONE NORTH OF COALINGA, CALIFORNIA[1]

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ABSTRACT

In 1937 the writer defined the Lodo formation exposed along the west side of the San Joaquin Valley, California, as a shale unit with an included sandstone member (Cantua sandstone). The formation is stratigraphically above the Moreno shale (Upper Cretaceous) and below the Domengine sandstone (middle Eocene).

The Domengine in that paper erroneously was considered to be the "Domijean sands" of F. M. Anderson (1905). It included the "Tejon" of Anderson and Pack (1915), or the restricted Domengine of Clark and the underlying sandstone referred by him to the Meganos. However, a critical reading of the original definition of Anderson's "Domijean sands" shows that it included all strata from the base of the Cantua sandstone member to the base of the Kreyenhagen shale of later workers. It is, therefore, an unsuitable cartographic term. The Domengine as redefined by Clark is a well defined mappable unit.

The name Yokut is here proposed for the sandstone unit that lies between the top of the Lodo shale and the pebble bed at the base of the Domengine as redefined by Clark. The Yokut is overlapped by the Domengine at the axis of Coalinga anticline on the south, and approximately one mile northwest of Tumey Gulch on the north. The lower contact of the Yokut is gradational with the underlying carbonaceous sandy siltstone in the upper part of the Lodo.

The type locality of the Yokut sandstone is near the west boundary of the SE. ¼, Sec. 29, T. 18 S., R. 15 E., M.D.B., in Domengine Creek where the formation is 45 feet thick. A maximum thickness of 305 feet was observed between Salt Creek and Martinez Creek.

Yokuts is the name of an Indian tribe who inhabited the San Joaquin Valley.

INTRODUCTION

The purpose of this paper is to discuss the stratigraphical relationships of the Eocene formations exposed between Oil City and Panoche Creek, and to establish a rational formational classification of them.

This classification is based on the superposition of lithologic units as contrasted to previous classifications, which were based mainly on the supposed correlations with previously named formations exposed in other areas.

LOCATION

The formations described in this paper are exposed in the low foothills that flank the eastern border of the Diablo Range on the western margin of the San Joaquin Valley, Fresno County, California. Their areal extent is from Los Gatos Creek, a few miles northwest of Coalinga, to a point 3 miles north of Panoche Creek. This is a distance of approximately 40 miles (Fig. 2).

[1] Read in part before the Sixth Pacific Science Congress at Berkeley, California, July 31, 1939. Published by permission of the chief geologist, Barnsdall Oil Company, Los Angeles, California. Manuscript received, March 4, 1940.

[2] Geologist, Barnsdall Oil Company.

ACKNOWLEDGMENTS

This work was commenced in 1937 and completed under the direction of Hubert G. Schenck, of Stanford University, who suggested the problem as a part of a more comprehensive project aiming at a biostratigraphic classification of the Eocene of the Pacific Slope of North America such as has already been set up for the Miocene and Oligocene. The writer is indebted to him, E. Wayne Galliher, and William D. Kleinpell for their suggestions and criticisms in the preparation of this report. He is also indebted to Robert M. Kleinpell, Richard E. Ten Eyck, Ottmar F. Kotick, Lesh Forrest, William Kennett, Edward C. Taber, and Robert Bayles, who have given detailed information on specific localities, or have given suggestions on the problems of stratigraphy that were presented.

STRATIGRAPHIC PRINCIPLES ADOPTED

Since there is a diversity of opinion and some confusion as to the difference between rock-stratigraphic and time-stratigraphic units,[3] it is deemed desirable to discuss the stratigraphic principles followed in this report. Lithology is the dominant factor in recognizing the rock-stratigraphic unit and paleontology the dominant factor in recognizing the time-stratigraphic unit.[4]

FORMATION[5]

A formation is the fundamental unit in rock-stratigraphic terminology. It is a lithogenetic and cartographic unit. It is composed of rocks of one lithologic type or of an alternation of types that in their heterogeneity constitute a form of unity. It represents deposits of a particular environment or an alternation of similar environments. A formation is recognized particularly by its characteristic lithology and also by its stratigraphic position and included fossils. It should be mappable in the field in order to show its relationship with subjacent and superjacent units and to aid in deciphering the structure of a region.

Areal extent.—A formation should bear the same name as far as it is mappable away from the type locality. However, it is a matter of judgment how far from the end of continuous outcrops from the type locality a formation may be called by the same name. Such judgment should be based on the characteristic lithology, stratigraphic relationships, and faunal content of the unit.

[3] Hubert G. Schenck and Robert M. Kleinpell, "Refugian Stage of Pacific Coast Tertiary," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 2 (February, 1936), p. 215.

[4] *Ibid.*, p. 216.

[5] See G. H. Ashley *et al.*, "Classification and Nomenclature of Rock Units," *Bull. Geol. Soc. America*, Vol. 44 (1933), pp. 423–59, Article 2 (4), Sections 2–4.

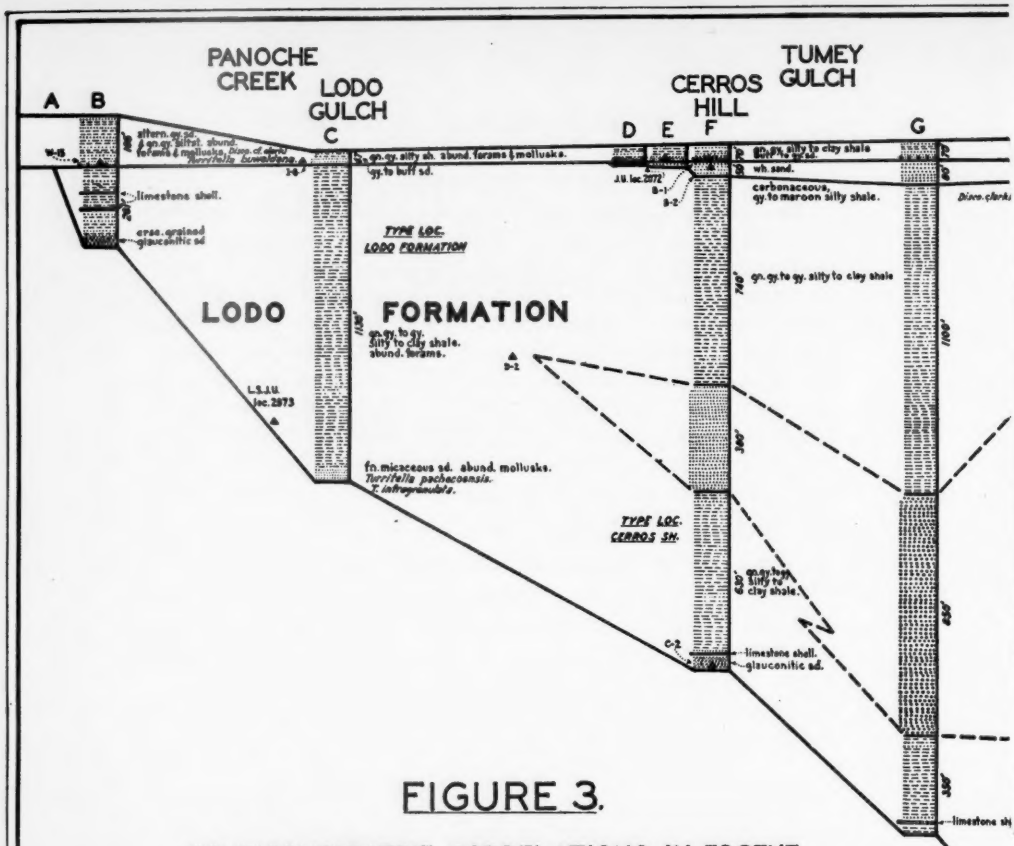

FIGURE 3.

SOME COMPARATIVE CORRELATIONS IN EOCENE NORTH OF COALINGA, FRESNO CO. CALIF.

F. M. ANDERSON 1905	F. M. ANDERSON 1908	ARNOLD & R. ANDERSON '10	DUMBLE 1912	R. ANDERSON & PACK 1915	DICKERSON 1916	CLARK 1926	ATWILL 1935	WHITE 1938	VOKES 1939	WHITE THIS REPORT	AGE
MONTEREY SHALE	UPPER SHALES	TEJON? FORMATION	TEJON FORMATION	KREYENHAGEN SHALES	OLIGOCENE SHALE / TEJON EOCENE	KREYENHAGEN SHALES	TUMEY FORM. SH. / SS. — KREYENHAGEN SHALE		TUMEY SHALE — KREYENHAGEN FORMATION	TUMEY SH. / TUMEY SS. — KREYENHAGEN SHALE	OLIG.
DOMENGINE SANDS; KREYENHAGEN SHALES	UPPER SANDS; LOWER SHALES	TEJON FORMATION; PURPLE SHALE	MARTINEZ FORMATION	TEJON FORMATION; MARTINEZ (?) FORMATION: CLAY SHALE, CANTUA SS. MEMB.	TEJON GROUP	DOMENGINE FORMATION; MEGANOS FORMATION: WHITE SS. MEMBER	DOMENGINE FORMATION; MEGANOS GROUP: SS. MEMBER, MEGANOS; MARTINEZ GROUP: CANTUA SS. MEMB., MARTINEZ SHALE	DOMENGINE FORMATION; LODO FORMATION: ARROYO HONDO SHALE MEMBER, CANTUA SS. MEMB., CERROS SHALE MEMBER	DOMENGINE FORMATION; ARROYO HONDO FORMATION: WHITE SS. MEMBER, RAGGED VALLEY SHALE MEMBER, CANTUA SS. MEMB., RAGGED VALLEY SHALE MEMBER	DOMENGINE FORMATION; LODO FORMATION: YOKUT SANDSTONE, ARROYO HONDO SHALE MEMBER, CANTUA SS. MEMB., CERROS SHALE MEMBER	PALEOCENE & EOCENE
KREYENHAGEN SHALES	LOWER SHALES	KIRKWOOD - CHICO UPPER DIVISION: PURPLE SHALE	CHICO GROUP	MORENO FORMATION	CHICO CRETACEOUS	MORENO	MORENO	MORENO	MORENO FORMATION	MORENO SHALE	CRETACEOUS
AVENAL SANDS	LOWER SANDS	SAND & SHALE	CHICO GROUP	PANOCHE FORMATION					PANOCHE FORMATION	PANOCHE FORMATION	

FIG. 1.—Geologic section *AG*, Fresno County.

FIG. 3.—Correlations in Eocene north of Coalinga, Fresno County.

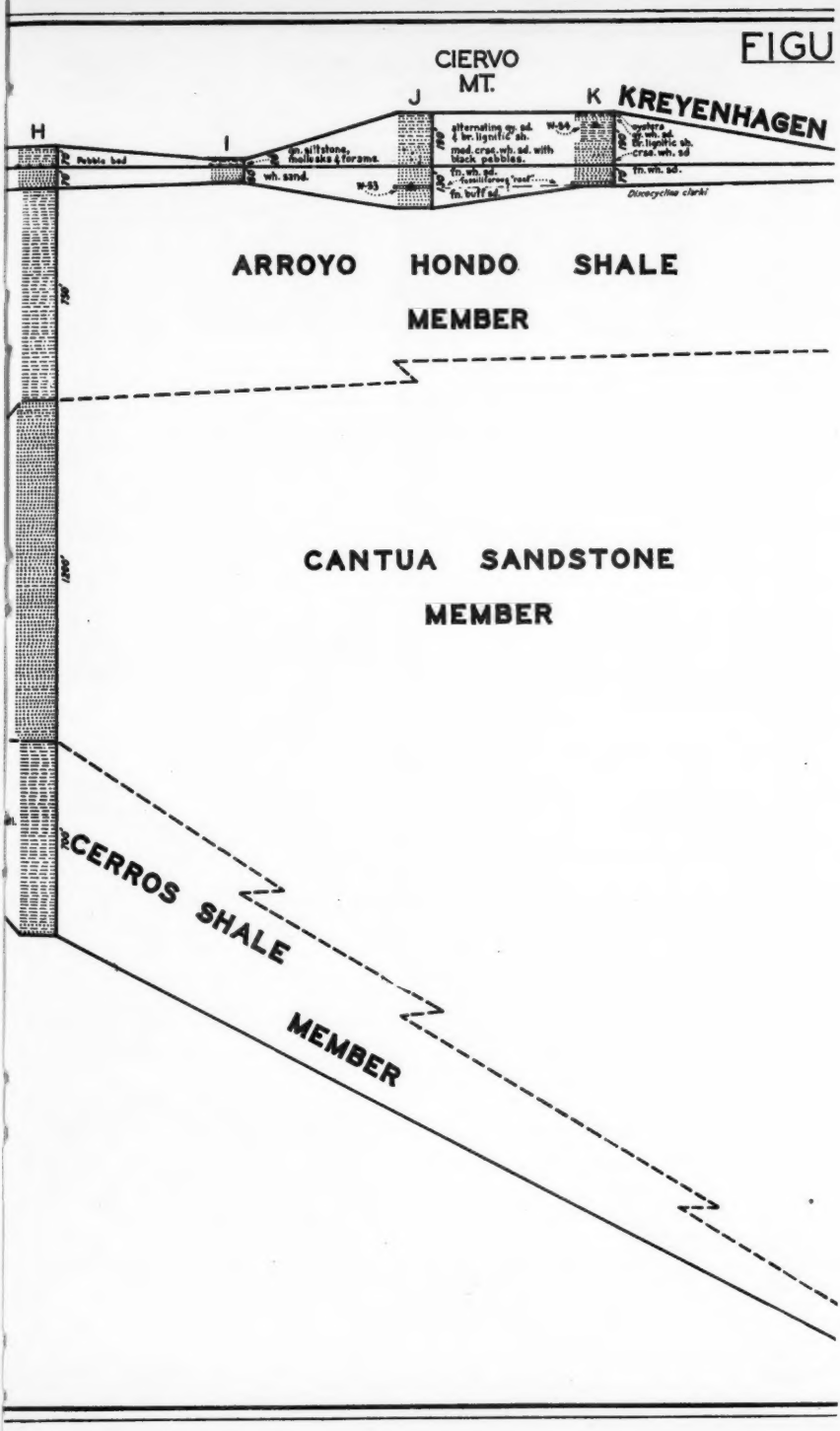

FIG. 1 (continued).—Geologic section *HK*.

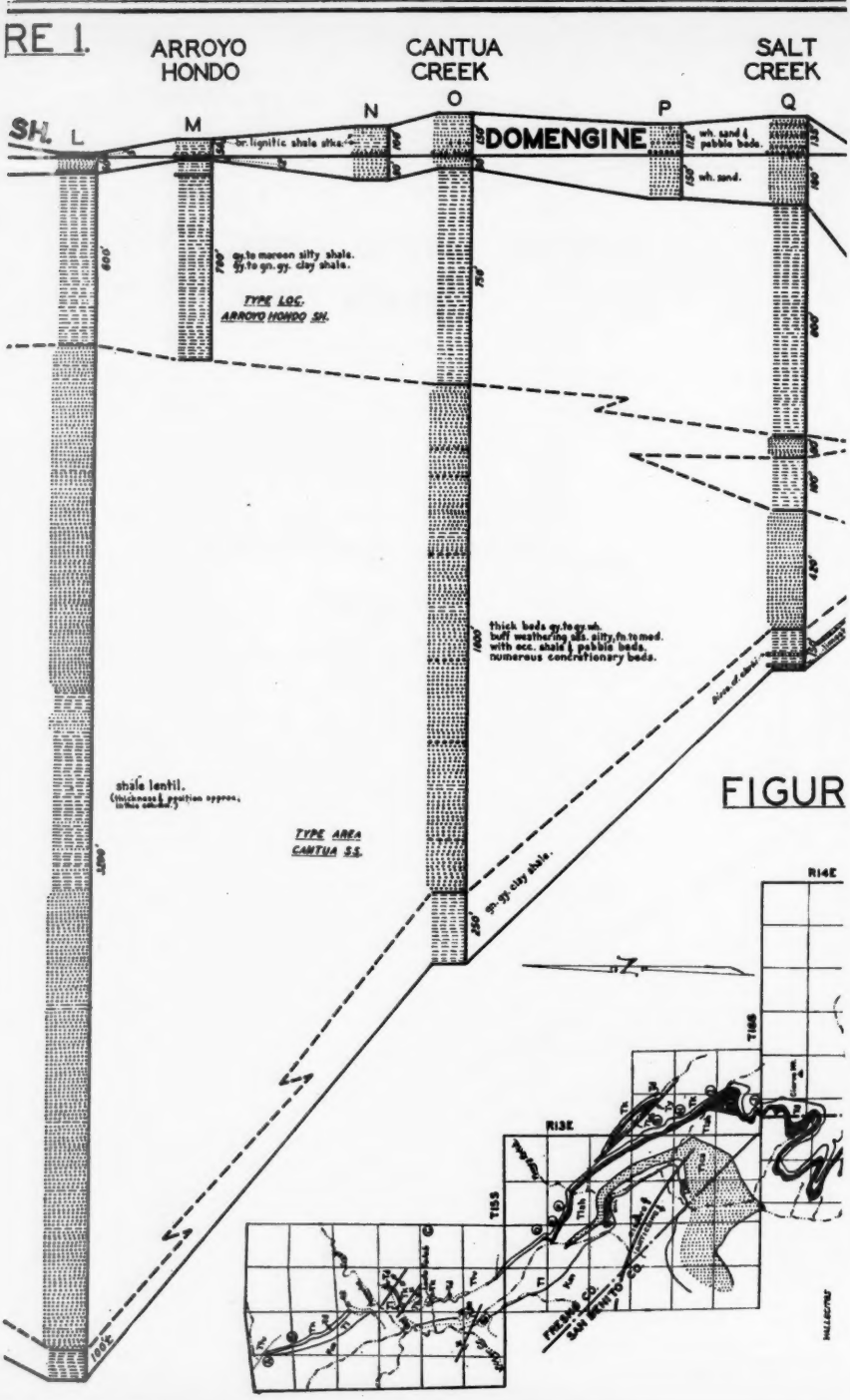

FIG. 1 (continued).—Geologic section *LQ*.

FIG. 2.—Geologic map of northwest part of area of geologic section (Fig. 1).

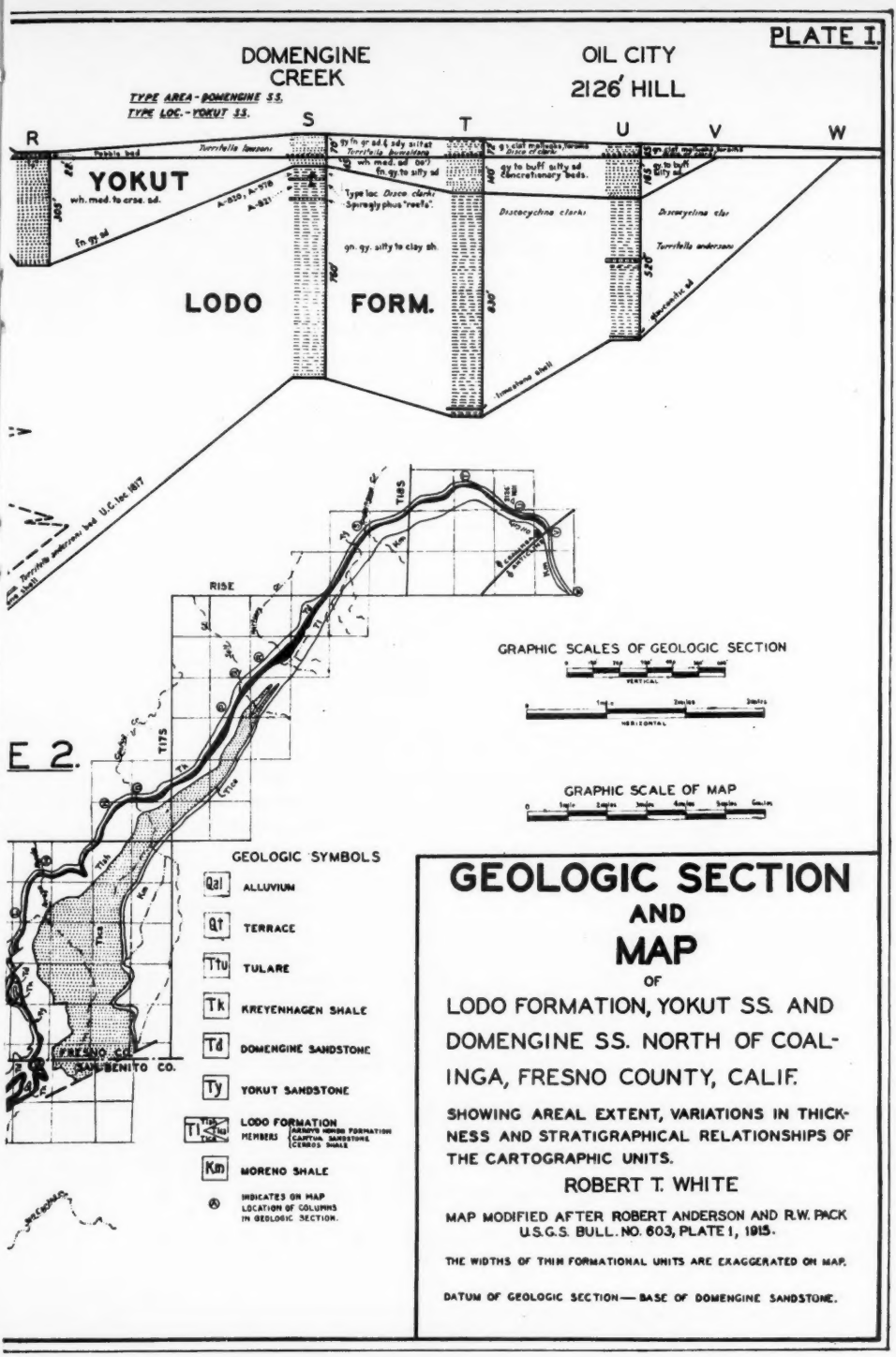

FIG. 1 (concluded).—Geologic section *RW*.

FIG. 2 (concluded).—Geologic map of southeast part of area of geologic section (Fig. 1).

Formational names should not be extended over widely separated areas merely because of a supposed age relationship. Such a correlation is speculative as it is based on an individual's interpretation of the range of certain faunas. This procedure has resulted in many name changes for the same unit due to the changing concepts as to its age. It has even resulted in restriction of "formations" at imaginary lines based on lowermost or uppermost occurrences of supposedly diagnostic fossils with no respect for lithologic or cartographic boundaries.

ZONE

A zone[6] is the fundamental unit in time-stratigraphic terminology. It is a unit of sedimentary rocks defined by paleontologic evidence, whereas physical criteria are those relied upon in defining a lithogenetic unit. A zone is a unit containing the rocks deposited during the existence of a particular faunal or floral assemblage of organisms, one of which is chosen as an index species, but such a species need not be confined to its zone or it need not be found everywhere throughout the zone. The index species is in no way governed by the lithologic character of the rock. A zone may be of the magnitude of part of a formation, a formation, or several formations.

HISTORICAL REVIEW

The purpose of this review is to show the development of the stratigraphic classifications within this particular area, and to indicate the necessity and practicability of differentiating between time-stratigraphic and rock-stratigraphic units (Fig. 3).

Nomenclature begins with 1905.—For the sake of brevity, only the most pertinent papers showing the evolution of the stratigraphic terminology of the Coalinga region are discussed. Although Whitney (1865),[7] (1869),[8] White (1885),[9] (1899),[10] Becker (1889),[11] Watts

[6] For excellent discussion of zones and stages, see R. M. Kleinpell, *Miocene Stratigraphy of California* (*Amer. Assoc. Petrol. Geol.*, 1938), pp. 89–99.

[7] J. D. Whitney, "Geology of California," *Geol. Survey California*, Vol. 1 (1865), pp. 1–498.

[8] ———, "Preface. Paleontology of California," *ibid.*, Vol. 2 (1869), pp. vii–xiv.

[9] C. A. White, "On the Mesozoic and Cenozoic Paleontology of California," *U. S. Geol. Survey Bull. 15* (1885), pp. 1–33.

[10] ———, "On Invertebrate Fossils from the Pacific Coast," *ibid.*, *Bull. 51* (1889), pp. 1–102.

[11] G. F. Becker, "Summary of the Geology of the Quicksilver Deposits of the Pacific Slope," *ibid.*, *8th Ann. Rept.* (1889), Pt. II-C, pp. 961–85.

(1894),[12] Turner and Stanton (1894),[13] Stanton (1896),[14] and Eldridge (1903)[15] noted the presence of Eocene deposits either in the vicinity of Coalinga or northward in the Vallecitos, this historical summary is commenced with the work of F. M. Anderson (1905),[16] who was the first person to give a detailed stratigraphic description of the area.

Avenal sandstone and Kreyenhagen shale.—South of Coalinga on Reef Ridge, F. M. Anderson recognized and named two lithologic units that he correlated with the Tejon. The lower is the Avenal sandstone, lying on the Cretaceous sandstone, and the upper is the Kreyenhagen shale. North of Coalinga on the basis of supposed stratigraphic position and lithologic similarities he erroneously correlated the Avenal sandstone with the upper part of the Panoche (Upper Cretaceous) sandstone; and the Kreyenhagen shale with the Moreno (Upper Cretaceous) shale and parts of the Lodo (Paleocene and Eocene) shale. The error probably was due to the absence of equivalents of the Moreno and Lodo shales south of Coalinga between the Cretaceous and Avenal sandstones. He called the sands above his "Kreyenhagen shale" north of Coalinga the "Domijean sands," which he believed to represent the uppermost Eocene deposits in this area. The white shales overlying the "Domijean sands" that are now correlated with the Kreyenhagen shale south of Coalinga were referred by Anderson to the Monterey shales.

Original definition of "Domijean sands."—The following is F. M. Anderson's description of the "Domijean sands."

> On the N.E. ¼ of Sec. 17, north of Coalinga, similar pebbly beds just above the top of the Kreyenhagen Shales contain a few of the foregoing species along with species of Foraminifera and nodules of barites.
>
> This horizon of the Eocene begins its greater development at this point and increases in thickness as it is followed to the northwest. On the east side of Section 17 it has a thickness of not more than three hundred fifty feet, while eight miles to the north west it has a thickness of something like twelve hundred feet, where it is exposed in the vicinity of the Kimball wells.
>
> It consists chiefly of yellow sands, which, as far as they have been followed, are but little consolidated, and under the meager rainfall of the region readily disintegrate, forming loose sandy slopes. Its great development in

[12] W. L. Watts, "The Gas and Petroleum Yielding Formations of the Central Valley of California," *California State Min. Bur. Bull. 3*, pp. 1–100.

[13] H. W. Turner and T. W. Stanton, "Notes on the Geology of the Coast Ranges of California," *Amer. Geol.*, Vol. 14, pp. 92–98.

[14] T. W. Stanton, "The Faunal Relations of the Eocene and Upper Cretaceous on the Pacific Coast," *U. S. Geol. Survey 17th Ann. Rept.* (1896), Pt. I-H, pp. 1005–60.

[15] G. H. Eldridge, "The Petroleum Fields of California," *ibid., Bull. 213* (1903), pp. 306–21.

[16] F. M. Anderson, "A Stratigraphic Study in the Mount Diablo Range of California," *Proc. California Acad. Sci.*, Ser. 3, Vol. 2, No. 2 (1905), pp. 162–68.

the vicinity of the Domijean ranch affords grounds for its designation as the *Domijean Sands*.[17]

The "Domijean sands" of F. M. Anderson was an unsuitable term as it included more units in one locality than in another. Thus on the east side of Section 17 in the vicinity of Oil City the 350 feet of strata assigned to it included the Domengine as restricted by Clark (1926)[18] and the underlying Yokut sandstone described in this paper, whereas eight miles north in the vicinity of the Kimball wells the 1,200-foot thickness of the "Domijean sands" had to include the Cantua sandstone and Arroyo Hondo shale members of the Lodo formation as well as the Yokut and Domengine.

F. M. Anderson (1908)[19] divided the Eocene deposits north of Coalinga into four lithologic units. The lowermost division, "Lower sands," was the equivalent of the "Avenal sands" of his former paper. He stated that no fossils were found in these sands and " . . . their classification as Eocene is based on other evidence than fauna."[20] His next division, "the Lower shales," was the equivalent of the Kreyenhagen shales of his 1905 paper and included what is now the Moreno (Upper Cretaceous) shale and, at Oil City, the whole of the Lodo (Paleocene and Eocene) formation and, at Cantua Creek, the Cerros shale member of that formation. He suggested a possible correlation with the Martinez based on fossils found in the western part of the Coalinga oil field and the occurrence of "*Turritella pachecoensis*" and associated fauna on a tributary of Salt Creek.[21] The third division, the "Upper sands," was the equivalent of his "Domijean sands." It contained the units previously mentioned and was given a thickness of 2,500 feet on Cantua Creek. The uppermost division, the "Upper shales," was the same as the "Monterey shales" of his 1905 paper. He recognized these shales as being " . . . Stratigraphically and structurally . . . connected closely with the Tejon series, while faunally they are allied more closely to the Miocene."[22]

[17] F. M. Anderson, *op. cit.*, p. 167.

[18] Bruce L. Clark, "The Domengine Horizon Middle Eocene of California," *Univ. California Pub. Bull. Dept. Geol. Sci.*, Vol. 16, No. 5 (1926), pp. 104–06.

[19] F. M. Anderson, "A Further Stratigraphic Study in the Mount Diablo Range of California," *Proc. California Acad. Sci.*, Ser. 4, Vol. 3 (1908), pp. 11–17.

[20] F. M. Anderson, *op. cit.*, p. 12.

[21] This latter locality is very likely the Univ. California Loc. 1817 that contains *Turritella andersoni* Dickerson, a species mistaken by F. M. Anderson for *Turritella pachecoensis* Stanton.

[22] F. M. Anderson, *op. cit.*, p. 16.

Arnold and Robert Anderson (1908)[23] (1910)[24] included the Avenal sandstone and Kreyenhagen shale south of Coalinga in their "Tejon formation." North of Coalinga, in the first paper, they included in their "Tejon formation" the purple shales (Moreno) together with the Lodo shale, Yokut and Domengine sandstones, and Kreyenhagen shale of present terminology. In the latter paper they recognized that the purple shales belonged to the Cretaceous.

Robert Anderson (1911)[25] referred to the Cretaceous the concretionary sandstone unit that he later named the Cantua sandstone member of the "Martinez (?) formation."

Dumble (1912)[26] described the occurrence of "Martinez" and "Tejon" in the Cantua-Salt Creek region. He stated:

> Our work now proves that this lower member of the Eocene is of very considerable extent southward on the west side of San Joaquin Valley; that it consists of three or more clearly defined members, and that, in addition to the unconformity already described between it and the Cretaceous, there also exists a decided unconformity between it and the overlying Tejon.

The first of these "members," his lower chocolate shale, included the Moreno and the Cerros shale member of the Lodo. The middle member, yellow sands and conglomerate with shale streaks, embraced the Cantua sandstone. The upper member, chocolate shale, is the equivalent of the Arroyo Hondo shale.

Dumble divided his "Tejon formation" into two divisions. The lower member was subdivided into a lower 20–40 feet of white sandstone and conglomerate with whitish shale inclusions at the base, and an upper 100–160 feet of yellowish to white, in most places fine-grained sand. The importance of these subdivisions is that the former approximates the thickness of the Yokut sandstone in this area, and the latter approximates the thickness of the restricted Domengine in this area. Dumble described an unconformity at the base of his lower subdivision instead of at the base of the upper subdivision (commonly called the "pebble bed"). However, in the vicinity of Oil City, he placed an unconformity between his "Martinez" and "Tejon" at the base of the "pebble bed" (base of restricted Domengine). This being

[23] Ralph Arnold and Robert Anderson, "Preliminary Report on the Coalinga Oil District, Fresno and Kings Counties, California," *U. S. Geol. Survey Bull. 357* (1908), pp. 23–29.

[24] ———, "Geology and Oil Resources of the Coalinga District, California," *ibid., Bull. 398* (1910), pp. 62–70.

[25] Robert Anderson, "Preliminary Report on the Geology and Oil Prospects of the Cantua-Panoche Region, California," *U. S. Geol. Survey Bull. 431* (1911), pp. 58–87.

[26] E. T. Dumble, "Notes on the Tertiary Deposits Near Coalinga Oil Field and Their Stratigraphic Relation with the Upper Cretaceous," *Jour. Geol.*, Vol. 20 (1912), p. 31.

the case, some authors, citing Dumble's evidence for an unconformity at the base of the restricted Domengine, have failed to differentiate between these two localities.

The upper division of Dumble's "Tejon" included white to pink shales with minor sandy strata in the lower two thirds. This is the Kreyenhagen shale of present terminology. Dumble stated that this upper division " . . . may in part or as a whole represent the Oligocene."[27]

Moreno shale.—Anderson and Pack (1915)[28] asserted that the purple shales, which most earlier workers placed in the Eocene, represented the uppermost Cretaceous exposed in the region north of Coalinga. They named this unit the Moreno shale from its typical exposures at Moreno Gulch. They questionably referred the shale unit between the Moreno and Yokut to the "Martinez" formation and stated:

> The faunas of both the lower and the upper beds contain many species that are present in the overlying Tejon, and on the whole both probably resemble the fauna of the Tejon as known in other regions more closely than they do that contained in the Martinez at the type section near San Francisco Bay. Yet, as these beds contain such lower Eocene fossils as *Turritella pachecoensis*, *Arca biloba*, and *Glycymeris veatchi* var. *major*, and rest unconformably below beds that contain a typical Tejon fauna, they can not well be mapped as Tejon and must either be designated by a new formation name or correlated tentatively with the Martinez until more evidence regarding their true position is available.[29]

Cantua sandstone.—This unit crops out from a point a short distance south of Salt Creek, around into the Vallecitos, and northward to a point a short distance north of Tumey Gulch.

Anderson and Pack noted the presence of a large sandstone lens in the lower part of their "Martinez (?)." This lens they called the Cantua sandstone from its typical exposures on Cantua Creek. They mapped the Cantua sandstone as the lower member of their "Martinez (?)" and included in the basal part of the Cantua 100 feet of dark brown to black clay shale that continues to the south of Salt Creek where it forms the lower part of the uniform body of their "Martinez (?)." They stated:

> The presence of such a shale below the sandstone serves to emphasize the lenticular nature of the sandstone mass as a great inclusion within a body of finer material.[30]

[27] E. T. Dumble, *op. cit.*, p. 33.

[28] Robert Anderson and Robert W. Pack, "Geology and Oil Resources of the West Border of the San Joaquin Valley North of Coalinga, California," *U. S. Geol. Survey Bull. 603* (1915), pp. 58–78.

[29] *Ibid.*, pp. 66–67.

[30] *Ibid.*, p. 62.

Anderson and Pack were of the opinion that their "Martinez (?)" lies unconformably on the Moreno, although the only structural evidence noted for this unconformity was exposed in a road cut on Panoche Creek. They referred the sandstones situated between their "Martinez (?)" shale and Kreyenhagen shale to the "Tejon" formation. They stated that the "Tejon" was unconformable with the "Martinez (?)" although no good example of discordance in dip at the contact of the two formations was observed. Their evidence for an unconformity was that the "Tejon" completely overlapped the "Martinez (?)" and lay on the Moreno west of Coalinga anticline and northwest of New Idria.

They also asserted that the Kreyenhagen shale probably unconformably overlies the "Tejon." Their best evidence for this unconformity was an absence of "Tejon" between their "Martinez (?)" and Kreyenhagen for a distance of five miles on the north side of the Vallecitos. Likewise they believed that a similar condition existed from the divide between Tumey Gulch and Silver Creek to a point two miles north of Panoche Creek. However, detailed work in that area has proved the presence of the restricted Domengine sandstone (equivalent to the upper part of Anderson and Pack's "Tejon").

Kreyenhagen shale.—They recognized that the white shale overlying their "Tejon" was similar in lithology and stratigraphic position to the Kreyenhagen shale of the Reef Ridge area. Therefore, they extended the limits of that formation to include these white shales north of Coalinga.

Dickerson (1916)[31] in discussing the stratigraphy and paleontology of the "Tejon group" in the Coalinga region based his stratigraphy on the earlier work of Dumble and made no reference to Anderson and Pack. Dickerson correctly pointed out the Cretaceous-Eocene contact was near the top of Dumble's "lower Martinez shale member" or at the Moreno-"Martinez (?)" contact of Anderson and Pack. He included all units between this contact and the lower third of the Kreyenhagen in his "Tejon group"; questionably referred the middle part of the Kreyenhagen to the "Tejon"; and assigned the upper part of the Kreyenhagen to the Oligocene. In discussing the unconformity between Dumble's "Martinez" and "Tejon," Dickerson said that it was of secondary importance such as might serve to separate two formations within a group.

Restricted Domengine formation.—Clark (1926)[32] restricted the "Do-

[31] Roy E. Dickerson, "Stratigraphy and Fauna of the Tejon Eocene of California," *Univ. California Pub. Bull. Dept. Geol.*, Vol. 9, No. 17 (1916), pp. 422–35.

[32] Bruce L. Clark, *op. cit.*, pp. 103–06.

mijean sands" of F. M. Anderson to the upper half of the "Tejon" as mapped by Anderson and Pack; corrected the spelling and called it the Domengine formation. He placed the lower half of Anderson and Pack's "Tejon" and their "Martinez (?)" in the "Meganos." Clark described a pebble bed resting unconformably on white sands as the base of the Domengine formation, and followed Anderson and Pack in believing the upper contact with the Kreyenhagen probably was unconformable.

Church (1931)[33] is the only one who has published a detailed description of the Domengine-Kreyenhagen contact. His description is as follows.

> On the southwest slope of the high hill at the head of the main east branch of Oil Canyon, northeast of Oil City, the basal chocolate-brown shales of the Kreyenhagen rest on the gray sandy-clay shale of the Domengine Eocene without any noticeable unconformity but the two formations are separated by a two-foot bed of gypsiferous clay and glauconitic sand. Eight feet above the contact, a gray clay-shale about twenty feet thick intervenes.[34]

Tumey formation.—Atwill (1935)[35] mapped the shale unit overlying the Moreno, and included in the Cantua sandstone by Anderson and Pack, as "Martinez" shale. He placed it together with the Cantua sandstone in the "Martinez group." He put the shale overlying the Cantua sandstone and the white sandstone underlying the Domengine in the "Meganos group." Atwill followed Clark's usage of the Domengine, but believed its upper contact with the Kreyenhagen was gradational. North of Arroyo Ciervo in the upper part of the Kreyenhagen Atwill mapped a large sand lens with an intervening shale between it and the overlying Temblor. He named this sand and overlying shale the Tumey formation and cited evidence to prove its Oligocene age.

The Kreyenhagen shale below the Tumey sand he placed in the Eocene.

Lodo formation, Cerros, and Arroyo Hondo shale members.—White (1937)[36] proposed the name Lodo for the "Martinez (?)" formation of Anderson and Pack. He noted that in the vicinity of Tumey Gulch this formation is separable into three members due to the presence of the Cantua sandstone lens. Cerros was proposed for the lower shale member, that was mapped with the Cantua sandstone by Anderson

[33] C. C. Church, "Foraminifera of the Kreyenhagen Shale," *California State Miner.*, Vol. 27, No. 2 (April, 1931), pp. 202–13.

[34] C. C. Church, *op. cit.*, p. 204.

[35] E. R. Atwill, "Oligocene Tumey Formation of California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 8 (August, 1935), pp. 1192–1204.

[36] Robert T. White, "Eocene Lodo Formation and Cerros Member of California," *Proc. Geol. Soc. America for 1937* (June, 1938), pp. 256–57.

and Pack, and was referred to as "Martinez" shale by Atwill. Arroyo Hondo was proposed for the upper shale member.[37]

Vokes (1939)[38] used the preoccupied term Arroyo Hondo to include most of the Lodo formation[39] and an unnamed sandstone unit between the Lodo and Domengine (Yokut sandstone of this paper). He termed this latter unit a white sandstone member of the "Arroyo Hondo formation." Vokes also proposed the term "Ragged Valley shale member" to include most of the Lodo shale, Cerros shale member, and Arroyo Hondo shale member, all of which were named and defined previous to his designation.

The classification proposed in this paper is compared graphically with previous classifications in Figure 3. In this figure the stratigraphic position of the Cantua sandstone is represented in each column whether or not it was recognized by the author whose classification is shown.

STRATIGRAPHY

The formations described in this report lie between the Moreno (Upper Cretaceous) shale and the Kreyenhagen (upper Eocene) shale. In descending order they are as follows.

Domengine sandstone
Yokut sandstone
Lodo formation
  Arroyo Hondo shale member
  Cantua sandstone member
  Cerros shale member

LODO FORMATION

NAME AND TYPE LOCALITY

Lodo was the name given by the writer (1938)[40] to the "Martinez (?)" formation of Anderson and Pack. The reasons for this name

[37] This was the first published description of the Arroyo Hondo shale. The name was first used by E. R. Atwill in an unpublished paper read before the ninth annual meeting of the Pacific Section of the American Association of Petroleum Geologists. Atwill described the Arroyo Hondo as a shale formation, with a white arkosic sandstone member at the top, lying between the Cantua sandstone and the restricted Domengine. White found that the Arroyo Hondo shale is genetically a part of the Lodo formation and relegated its rank to a member and excluded from it the white sandstone unit.

[38] Harold Ernest Vokes, "Molluscan Faunas of the Domengine and Arroyo Hondo Formations of the California Eocene," *Ann. New York Acad. Sci.*, Vol. 38 (1939), pp. 1–38.

[39] On the south side of Panoche Creek Paleocene mollusks occur in sandy beds at the base of the Lodo which is the same as the base of the "Martinez (?)" of Anderson and Pack. Vokes apparently placed the base of his "Arroyo Hondo," which he correlates with the Capay, at some imaginary line above these sands, as he remarked that Anderson and Pack erroneously included these sands, containing Paleocene mollusks, in their "Martinez (?)." Actually a study of the field relationships of this locally developed sand facies clearly demonstrates that it is an integral part of the Lodo formation ("Martinez (?)" of Anderson and Pack).

[40] Robert T. White, *op. cit.*, p. 257.

change were: (1) the name Martinez is preoccupied by the Martinez formation exposed in an area more than 100 miles farther north on the east flank of Pacheco syncline in Contra Costa County; (2) the lithology of the type Martinez and Lodo formations is dissimilar; (3) these two formations are not traceable into each other; (4) Lodo is the name applied to a lithologic unit exposed in a definite geographical area, while "Martinez (?)" was a name applied to a lithologic unit on the basis of a questionable correlation with a previously named unit in another area.

The type locality of the Lodo formation is in a small gulch on the east side of Silver Creek, 4,000 feet south of the confluence of that creek with Panoche Creek, near the south line of the NE. $\frac{1}{4}$, Sec. 29, T. 15 S., R. 12 E., M. D. M. As no geographical names were available the small gulch was named Lodo Gulch and the formation named after it.

LITHOLOGY

The formation (excluding the Cantua sandstone lens) varies in texture from a claystone to a siltstone. It is gray in color, with bluish to greenish cast; is massive and dense, with a blocky fracture. The formation is commonly glauconitic; and is abundantly foraminiferal. The basal beds at the junction of Silver and Panoche creeks consist of approximately 50 feet of sand which is gray to buff-colored; fine-grained; micaceous; massive to semi-platy; friable to firmly cemented. Rare glauconitic sand streaks and a few thin beds of dark gray to black mudstone containing arenaceous Foraminifera are present. This sand grades into the overlying claystone. The lower ten feet of sand from Panoche Creek southward for a mile is abundantly fossiliferous and contains a few coarse sand grains and pebbles. Some of the pebbles are composed of maroon-colored shale similar in lithology to the underlying Moreno.

From Panoche Creek northward for a distance of 3 miles to the point where the Lodo is completely overlapped by the Domengine, the formation becomes increasingly more sandy. Due to the massive character of the Lodo it is difficult to tell whether the shales are grading laterally into a sandy facies or whether lower sand beds are making their appearance. A combination of the two conditions is likely. Evidence for a lateral change from shale to sand is that immediately north of Panoche Creek above the basal sand beds are a few thin sandstone layers interbedded with much thicker bodies of shale, while 2 miles farther northward the basal sand has thickened considerably, and contains a few shale beds in the upper part of it. Evidence favoring the appearance of lower sands is that a thin foraminiferal reddish

brown mudstone bed a few feet in thickness occurs 80 feet above the base of the formation at Lodo Gulch, and 210 feet above the base in the SW. ¼, Sec. 5, T. 15 S., R. 12 E., 3 miles north. It can not be proved that this mudstone is the same at both localities as it could not be traced continuously between them. However, a detailed examination of the lithology in both of these sections and in several intervening gullies disclosed the presence of only one such characteristic bed. Further evidence favoring the appearance of older sands north of Panoche Creek is that at Panoche Creek the contact between the Lodo and Moreno is disconformable whereas 2 miles farther north one sees no indication of an erosional surface between the two formations.

From 2 miles south of Panoche Creek to the southernmost outcrop of the Lodo west of Oil City, the basal sands occur as isolated patches and as thin sandstone beds interbedded with shale.

A limestone bed 1–2 feet thick and from 10 to 50 feet above the base of the Lodo was noted in a number of places between Panoche Creek and Ciervo Mountain. There are similar occurrences of it in the vicinity of Domengine and Salt creeks, and one well drilled on the western border of the San Joaquin Valley in this area in Sec. 1, T. 19 S., R. 15 E., reported a limestone at a depth of 7,333 feet in the same stratigraphic position, a few feet above the top of the maroon shales of the Moreno.

Another stratum found in the lower part of the Lodo in the vicinity of Salt Creek is a glauconitic sandstone bed 1–2 feet thick and ordinarily from 50 to 75 feet above the base of the Lodo. Locally this bed is very fossiliferous and is known as the "*Turritella andersoni* bed." Because of the slumping nature of the clay shales of the Lodo it is impossible to trace continuously such thin strata as the aforementioned limestone bed and "*Turritella andersoni* bed."

The upper 40–50 feet of the Lodo immediately below the Yokut sandstone is ordinarily silty to fine sandy with much finely disseminated carbonaceous material that commonly imparts a reddish brown cast to the rock. Small mollusks are common and *Discocyclina clarki* is very abundant locally. At Domengine Creek two hard fine-grained calcareous sandstone beds containing abundant *Spiroglyphus* sp. occur 40 and 100 feet, respectively, below the top of the Lodo.

Cantua sandstone.—The Cantua sandstone makes its appearance in Sec. 10, T. 16 S., R. 12 E., as a lens in the Lodo formation and is traceable to a mile south of Salt Creek where it ends in several tongues. This member separates the Lodo into two other mappable units, the Cerros shale member (lower) and the Arroyo Hondo shale member (upper).

The Cantua sandstone member was named by Anderson and Pack.[41] It is composed mainly of thick beds of massive sandstone in many places with a thin gray silty shale parting ranging from a fraction of an inch to several feet in thickness separating the sandy beds. Anderson and Pack state that locally there are clay shale bodies several hundred feet in thickness contained within the member. The sands weather to a buff or brown color and are gray to almost white on fresh surfaces. They are predominantly fine- to medium-grained although there are a few thin pebble beds.

Cerros shale.—Cerros was the name given by the writer (1938)[42] to the shale member below the Cantua sandstone and above the Moreno shale. Anderson and Pack[43] recognized the presence of this unit although they mapped it as the basal part of the Cantua sandstone.

The type locality of the Cerros shale member is on Cerros Hill on the west side of Tumey Gulch at the W. $\frac{1}{4}$ corner, Sec. 14, T. 16 S., R. 12 E., M. D. B. and M. As no names were available for this member it was necessary to name this conspicuous hill, where the member is typically exposed, and then name the member after it.

Lithologically the Cerros is identical with the Lodo and is recognizable as a distinct cartographic unit only where it is overlain by the Cantua sandstone.

Arroyo Hondo shale.—Arroyo Hondo, as pointed out in footnote 37 on page 1735, was the term adopted by the writer (1938)[44] from the unpublished report of Atwill for the upper shale member of the Lodo.

The type locality of the Arroyo Hondo shale member is on the creek of the same name in the S. $\frac{1}{2}$, Sec. 14, T. 17 S., R. 13 E., M. D. B. and M.

Like the Cerros shale, the Arroyo Hondo shale is lithologically identical with the Lodo and can be recognized as a distinct cartographic unit only where it is underlain by the Cantua sandstone lens.

FORMATIONAL BOUNDARIES

The Lodo formation is underlain throughout its areal extent by the Moreno (Upper Cretaceous) shale. At Panoche Creek near the type section of the Lodo, the contact between the basal sands of the Lodo and the maroon-colored shales of the Moreno is sharp with sand-filled erosion gutters cut into the underlying shale. The sand also contains scattered shale pebbles similar in lithology to the Moreno.

[41] R. Anderson and R. W. Pack, *op. cit.*, pp. 59–62.

[42] Robert T. White, *op. cit.*, p. 257.

[43] R. Anderson and R. W. Pack, *op. cit.*, pp. 61–62.

[44] Robert T. White, *op. cit.*, p. 257.

The lower 3 feet of the Cerros shale at its type locality on the south side of Cerros Hill is composed of a glauconitic sand with a dark gray clay shale matrix which grades upward into a claystone with scattered glauconite grains. This lower bed rests on the undulatory surface of the maroon-colored Moreno shale into which are cut small well defined erosion gutters. North of Panoche Creek no evidence of a disconformable contact was noted.

Due to the great amount of slumping of the "soapy" claystone in the lower part of the Lodo and Cerros shale, it is impossible to study the lower contact of the formation and the Cerros member in sufficient detail to determine from field relationships alone whether or not this is a conformable contact. However, paleontologists of some oil companies, who have collected foraminiferal samples across this contact at a number of different localities, report that on the basis of their faunal zones the stratigraphic position of the contact varies.[45]

Likewise foraminiferal samples collected by the writer from the lower 10 feet of Lodo at Oil City on the axis of Coalinga anticline in the N. ½, Sec. 20, T. 19 S., R. 15 E., contained the same foraminiferal assemblage that first appears more than 300 feet above the base of the Lodo at its type locality.

The lower and upper boundaries of the Cantua sandstone with the Cerros shale and Arroyo Hondo shale members of the Lodo in no sense represent stratigraphic horizons. Although in places these contacts between sandstone and shale are sharp, in other places they are gradational, representing a lateral change from sandstone to shale and *vice versa* (Fig. 1).

The upper contact of the Lodo and its Arroyo Hondo shale member with the overlying Yokut sandstone is gradational and in places this change from shale to sand is so gradational that the contact between the two must be drawn arbitrarily. In the north and south ends of the area the Yokut is completely overlapped by the Domengine sandstone which progressively overlaps the whole of the Lodo to rest on the Moreno (Figs. 1 and 2, sections DA and VW).

THICKNESS

The Lodo formation, 1,130 feet thick at its type locality, varies in thickness from zero at the north and south ends of its exposures, where

[45] On the 1939 spring field trip of the Society of Economic Paleontologists and Mineralogists to Coalinga, Glenn C. Ferguson, paleontologist, Union Oil Company, Bakersfield, California, who was conductor of the trip, stated that lower faunal zones were present at the base of the Lodo in the vicinity of Oil City than were present farther west near the end of Lodo outcrops. This indicates that in this area the Lodo is progressively overlapping the Moreno toward the west.

it is overlapped by the Domengine, to more than 5,000 feet a short distance east of San Carlos Creek. At the latter point the Cantua sandstone member alone has a thickness of approximately 4,500 feet. North and south of this point the Cantua lenses out into shale until it is com-

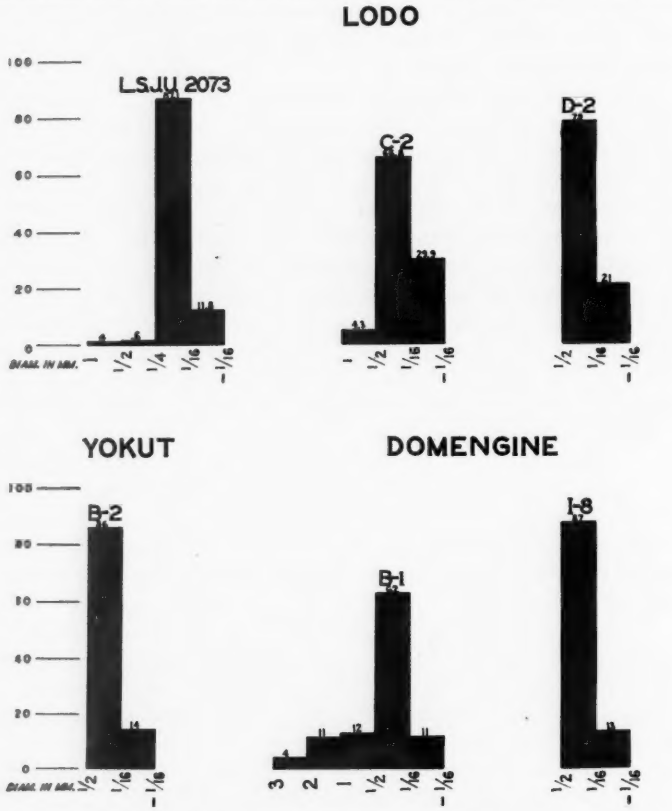

FIG. 4.—Histograms of some Eocene sands. Percentages of different grain sizes in samples D-2, I-8, B-2 made after removal of $CaCO_3$, which amounted to 25 per cent of total weight of each sample.

pletely gone a short distance north of Tumey Gulch and south of Salt Creek. The Cantua appears to have been deposited in a structural basin that was subsiding during its deposition, while the areas north and south remained relatively stable. As a result, the sands thinned within a short distance on the flanks of the basin and finally graded laterally into shale.

The Cerros shale, 680 feet thick at its type locality, varies from approximately 100 to 700 feet in thickness.

The Arroyo Hondo shale, 700 feet thick at its type locality, varies from approximately 500 to 1,100 feet in thickness. Its minimum thickness in the eastern end of the Vallecitos is due to the continued deposition of sands of the Cantua sandstone while shale was being deposited contemporaneously on the north and south.

MINERALOGY[46]

The abundance of black opaque minerals, zircon and epidote, in a sand sample from L. S. J. U. Locality 2073, Sec. 29, T. 15 S., R. 12 E., at the base of the Lodo suggests a granitic source. Also the presence of glaucophane indicates that at least some material was derived from the Franciscan formation.

The high percentage of feldspar, as well as the angularity and fresh appearance of all mineral grains, indicates a direct origin and not a reworked sediment. However, no suitable explanation can be offered for the abundance of fresh angular feldspar grains and at the same time the relatively small amount of ferro-magnesian minerals. The lack of abundant ferro-magnesian minerals might be explained by intense chemical weathering prior to deposition. But it is difficult to account for the large amount of fresh feldspars, as feldspar is ordinarily one of the first minerals lost during the cycle of erosion and deposition.

The sorting of the sand sample from L. S. J. U. Locality 2073 is excellent. By weight, 87.1 per cent of the sand had a grain size between 0.25 and 0.06 millimeter (Fig. 4). This high degree of sorting and associated coquina is suggestive of strand-line deposition.

A glauconitic sand sample from the basal part of the Cerros at Locality C-2, Sec. 15, T. 16 S., R. 12 E., contained a heavy-mineral suite nearly identical with that of the previous sample.

By weight, 89.9 per cent of the sample is composed of glauconite and almost all of the sand grains are composed of that mineral. The large amount of biotite in the sample from L. S. J. U. Locality 2073 and the abundance of glauconite in the sample from Locality C-2 (Table I) can best be explained by the transformation of biotite into glauconite.[47]

[46] The following mechanical and mineral analyses of sands from the Lodo and younger formations were made by Robert E. Bayles and the writer. The interpretations are mainly those of Bayles. The samples analyzed are far too few and are all from too small an area to make any but the broadest statement on the possible origin of the sediments.

[47] E. Wayne Galliher, "Geology of Glauconite," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 11 (November, 1935), pp. 1569–1601.

A sample from a sand lens in approximately the same stratigraphic position as the Cantua sandstone from Locality D-2, Sec. 4, T. 15 S., R. 12 E., differs mainly from the foregoing samples by the small amount of biotite or its alteration product, glauconite; and by the presence of garnet, hornblende, and magnetite.

TABLE I

MINERALOGICAL ANALYSES (PERCENTAGE)

Heavy Minerals	*Lodo*			*Yokut*	*Domengine*	
Sp. Gr. > 2.88	*2073*	*C-2*	*D-1*	*B-2*	*B-1*	*I-8*†
Black opaque	54	62	29		39	40
Magnetite			P		P	P
Epidote	10	2	6		6	
Zircon	28	27	26	26	29	45
Tourmaline	1	2	9	6	18	10
Rutile	1				2	1
Garnet			1		1	
Hornblende			2		1	
Glaucophane	2				1	P
Biotite	3	3	6			
Chlorite	1	31	15			3
Hematite				68	2	
Titanite					1	P
Sp. Gr. > 2.88 Per Cent Sample	.78	.3	1.7	.1	.6	4
Light Minerals Sp. Gr. < 2.88						
Quartz	42	8	*	*	*	*
Orthoclase	52	3	*	*	*	*
Plagioclase	6					
Glauconite		89				
Biotite	x					

P Present (less than 1 per cent).
* See footnote 60, page 1746.
x Practically all of the biotite remained with minerals having sp. gr. < 2.88. Minerals with sp. gr. > 2.88 plus biotite would equal 3.34 per cent by weight of sample.
† Position of samples shown in Figure 1, and exact locations are given in Register of Localities, p. 1751.

PALAEONTOLOGY

A study of the Mollusca of the Lodo indicates that it ranges in age from Paleocene to middle Eocene.

The sandy beds at the base of the Lodo at L. S. J. U. Locality 2073 contain a well preserved fauna similar to that of the basal part of the type Martinez formation. Some of the characteristic species are as follows.

Cucullaea mathewsoni Gabb
Glycimeris veatchii major Stanton
Ampullina pinyonensis Dickerson
Brachysphingus gabbi Stewart
Heteroterma cf. *gabbi* Stanton
Priscoficus caudatus (Gabb)
Tornatellaea pinguis (Gabb)
Turritella pachecoensis Stanton
Turritella infragranulata Gabb
Flabellum remondianum Gabb

Another important molluscan faunule has been described and figured by Dickerson[48] and by Vokes[49] from a short distance south of Salt Creek at University of California Locality 1817. This is the "*Turritella andersoni* bed" which at this point is 50 feet above the base of the Cerros shale and 100 feet below its upper contact with the Cantua sandstone. Clark and Vokes,[50] Merriam and Turner,[51] and Vokes[52] have correlated this faunule with that of the type Capay formation, "E" division of the type Meganos, and several other localities, all of which they include within their "Capay stage."

A third important molluscan faunule has been described by Vokes from the upper few feet of the Lodo in the vicinity of Domengine Creek,[53] which contains a fauna 85–93 per cent similar to the fauna of the Domengine.[54]

It is impossible to postulate unconformities and accurately delimit the various "stages" in the stage classification of Clark and Vokes[55] in the region north of Coalinga on the basis of Mollusca alone for the following reasons: (1) the fauna on which the Martinez has been correlated with the Midway of the Gulf Coast[56] and on which the "Martinez stage"[57] has been erected occur in the lower part of the Martinez formation, while Putlitz[58] has recently collected a "Capay" fauna from the top of the Martinez formation; (2) there is no published strati-

[48] Roy E. Dickerson, *op. cit.*, pp. 363–524, Pls. 36–46.

[49] Harold Ernest Vokes, *op. cit.*, pp. 1–246, Pls. 1–22.

[50] B. L. Clark and H. E. Vokes, "Summary of Marine Eocene Sequence of Western North America," *Bull. Geol. Soc. America*, Vol. 47, No. 6 (1936), pp. 858–61.

[51] C. W. Merriam and F. E. Turner, "The Capay Middle Eocene of Northern California," *Univ. California Pub. Bull. Dept. Geol. Sci.*, Vol. 24, No. 6 (1937), pp. 91–114.

[52] Harold Ernest Vokes, *op. cit.*, pp. 27–36.

[53] *Idem*, *op. cit.*, p. 188. Localities A-820, A-821, A-978, 4178.

[54] *Idem*, *op. cit.*, pp. 31–32. "Of the 31 species in the upper zone of the Arroyo Hondo, only 27 are fully determinable and all but 4 of these are also present in the Domengine fauna. These 4 are: *Corbula rosecanyonensis*, *Periploma eodiscus*, *Exilia taliaferroi*, *Galeodea susanae*. *Corbula rosecanyonensis* is known from the shales of the La Jolla formation near San Diego. Its absence and that of *Periploma eodiscus* in the Coalinga area is possibly to be explained as due to ecologic factors, since the upper zone of the Arroyo Hondo is a shale facies and the Domengine fauna is from sandstones. The genera *Exilia* and *Galeodea* are represented in all three recognized faunal horizons by distinct species which are absent in any of the other horizons."

[55] B. L. Clark and H. E. Vokes, *op. cit.*, pp. 851–78.

[56] Charles E. Weaver, "Contribution to the Paleontology of the Martinez Group," *Univ. California Pub. Bull. Dept. Geol.*, Vol. 4 (1905), pp. 101–23. Roy E. Dickerson, "Fauna of the Martinez Eocene of California," *ibid.*, Vol. 8, No. 6 (1914), pp. 61–180.

[57] B. L. Clark and H. E. Vokes, *op. cit.*, pp. 854–56.

[58] Fritz H. Putlitz, "Stratigraphy of the Type Martinez Formation, California," abstract presented at Sixth Pacific Science Congress at Berkeley, California (1939). From a thesis in partial fulfillment of the requirements for the M.A. degree, Stanford University.

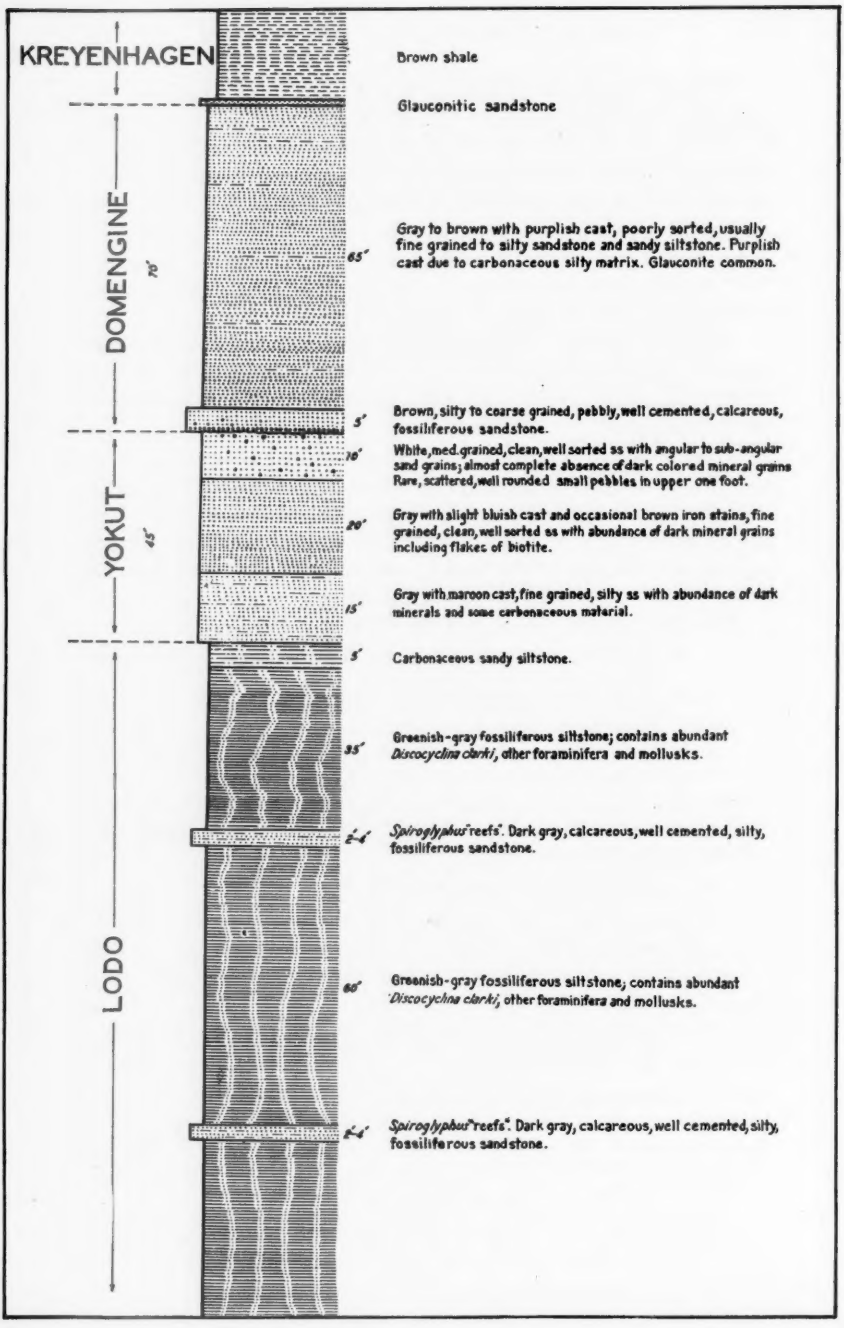
KREYENHAGEN
Brown shale
Glauconitic sandstone
DOMENGINE
70'
65'
Gray to brown with purplish cast, poorly sorted, usually fine grained to silty sandstone and sandy siltstone. Purplish cast due to carbonaceous silty matrix. Glauconite common.
5'
Brown, silty to coarse grained, pebbly, well cemented, calcareous, fossiliferous sandstone.
10'
White, med. grained, clean, well sorted ss with angular to sub-angular sand grains; almost complete absence of dark colored mineral grains Rare, scattered, well rounded small pebbles in upper one foot.
YOKUT
45'
20'
Gray with slight bluish cast and occasional brown iron stains, fine grained, clean, well sorted ss with abundance of dark mineral grains including flakes of biotite.
15'
Gray with maroon cast, fine grained, silty ss with abundance of dark minerals and some carbonaceous material.
5'
Carbonaceous sandy siltstone.
35'
Greenish-gray fossiliferous siltstone; contains abundant *Discocyclina clarki*, other foraminifera and mollusks.
2'-4'
Spiroglyphus reefs. Dark gray, calcareous, well cemented, silty, fossiliferous sandstone.
LODO
60'
Greenish-gray fossiliferous siltstone, contains abundant *Discocyclina clarki*, other foraminifera and mollusks.
2'-4'
Spiroglyphus reefs. Dark gray, calcareous, well cemented, silty, fossiliferous sandstone.

FIG. 5.—Columnar section at type locality of Yokut sandstone.

graphic control for the type Capay formation on which the "Capay" stage is erected; (3) there are no sandy beds above the beds containing the Paleocene faunule at L. S. J. U. Locality 2073 in which "Meganos" fossils might occur.

YOKUT SANDSTONE

NAME AND TYPE LOCALITY

Yokut is the name proposed by the writer[59] for the sandstone unit lying between the Lodo formation and Domengine sandstone. As no geographic names were available, Yokut was named after the Yokuts Indians who inhabited the San Joaquin Valley.

The type locality of the Yokut sandstone is near the west boundary of the SE. $\frac{1}{4}$, Sec. 29, T. 18 S., R. 15 E., M. D. B. and M., at the southernmost point at which that sandstone lies wholly on the east bank of Domengine creek (Fig. 5).

This unit was the lower part of the "Tejon" of Anderson and Pack (1915); was referred to the "Meganos" group by Clark (1921), (1926), and by Atwill (1935). The Yokut was incorrectly included in the Domengine by White (1938); it was likewise erroneously included in the Arroyo Hondo by Vokes (1939).

LITHOLOGY

The upper part of the Yokut sandstone is predominantly white, medium to very fine-grained, clean and well sorted with an extremely small percentage of dark minerals. It grades downward into sandstone that is gray to pinkish gray due to the presence of carbonaceous material. The sandstone is fine-grained to silty and is somewhat micaceous. From Domengine Creek south to the end of its outcrop the whole Yokut consists of very fine-grained silty sand. The sandstone is massive with here and there hard, well cemented layers and fossiliferous concretions. From the south side of Ciervo Mountain, around to the west and to the north of it (Figs. 1 and 2), there is a fine-grained, hard, limy, fossiliferous sandstone reef, 1–3 feet thick, that contains mollusks and large Foraminifera. This appears to be one continuous "reef" and has been observed as far west as San Carlos Creek where it lies at the base of the Yokut sandstone. In other places it occurs as much as 60 feet above the base.

FORMATION BOUNDARIES

The gradational contact between the Lodo and Yokut has already been discussed. That this contact does not follow a stratigraphic hori-

[59] Read in part before the Sixth Pacific Science Congress at Berkeley, California, July 31, 1939.

zon is indicated by the presence of the fossiliferous bed (mentioned in the preceding paragraph) at the base of the Yokut sandstone in one place and 60 feet above the base in another.

The upper boundary of the Yokut, throughout most of its outcrop, is an erosional surface on which rests the Domengine sandstone. The Domengine sandstone completely overlaps the Yokut sandstone a short distance north of Tumey Gulch and at the axis of the Coalinga anticline. For a distance of approximately 2½ miles both north and south of Salt Creek there is no evidence of an erosional contact between the Yokut and Domengine. The prominent pebble bed at the base of the latter can easily be traced through this region, yet there are scattered pebbles below it that extend from 5 to 20 feet down into the underlying formation. In this area the Yokut sandstone has a somewhat coarser texture and reaches its maximum development.

The white sands of the Yokut appear to be overlapped just south of Domengine Creek and are represented beyond that point by a fine-grained to silty gray sand which appears to be thickening at the expense of the underlying shale. Concretionary layers in this sand converge toward the south with the basal pebble-bed reef of the Domengine, indicating an overlap by the latter unit. A regional study of the geology bears this out.

The basal platy, carbonaceous, silty sands of the Yokut sandstone in Tumey Gulch can be traced almost continuously for 1½ miles northwest where they are overlapped by the Domengine.

THICKNESS

The Yokut sandstone varies from zero to 305 feet in thickness. Its greatest thickness is reached in the vicinity of Salt Creek where it appears to be conformable with the overlapping Domengine. At the type locality of the Arroyo Hondo shale it thins locally to 12 feet.

MINERALOGY[60]

Sample B-2 in Table I shows the great contrast in mineral suites between the Yokut sands and sands of the subjacent Lodo and superjacent Domengine. The sample is characterized by an extremely low percentage of heavy minerals. Zircon and tourmaline are the only heavy minerals present in addition to hematite, which composes 68 per cent of the total.

[60] Unfortunately at the time these analyses were made (March, 1937) the writer did not have in mind the possibilities of a mineralogical correlation with the Ione sandstone on the east side of the San Joaquin Valley, and did not, therefore, note the quartz-feldspar ratio or search diligently for anauxite. The cloudiness of some of the quartz grains and of some of the orthoclase grains would have made such a ratio difficult to ascertain. However, of the readily determinable grains, quartz was more abundant than orthoclase, but by no means sufficiently so to constitute a quartz sand.

If it is assumed that the Yokut and Ione sandstones were deposited contemporaneously from a common source in the Sierra Nevadas and the paucity of ferro-magnesian minerals is due to intense chemical weathering as suggested by V. T. Allen,[61] it is difficult to explain the relative abundance of the normally easily weathered orthoclase in the Yokut and the minor amount of it in the Ione. The most likely answer is that there was a mixing of sediments from the Sierra Nevadas and from sources on the west.

PALEONTOLOGY

The fossiliferous "reef" (Locality W-53) mentioned in the discussion on lithology and formational boundaries contains a molluscan faunule similar to the one noted by Vokes[62] in the upper part of the Lodo in the vicinity of Domengine Creek. It seems likely that they belong in the same zone and that the formational boundary transgresses this zone.

DOMENGINE SANDSTONE

NAME AND TYPE LOCALITY

As indicated in the historical review in this paper the original "Domijean sands" of F. M. Anderson was an unsuitable cartographic term. In 1926 Clark corrected the spelling and restricted the Domengine formation to include only the sands between the Kreyenhagen shale and the base of a "pebble bed" that was near the middle of the "Tejon" of Anderson and Pack. This formation, as restricted by Clark, is a well defined lithogenetic and cartographic unit. However, it is unfortunate that he chose a name that had been previously used to include more units. Although Clark did not designate a specific type locality, his original description was based on exposures in the vicinity of Domengine Ranch.

LITHOLOGY

In describing the lithology in the vicinity of Domengine Ranch, Clark states,

> The Domengine formation in this section is not much over 100 feet in thickness. It is composed very largely of yellow-brown, medium-fine to coarse, fossiliferous sandstone. At the base of the formation is a thin bed of well rounded conglomerate characterized by the large number of black chert pebbles.[63]

From the NW. ¼, Sec. 36, T. 19 S., R. 14 E., northward almost to

[61] Victor T. Allen, "Ione Formation of California," *Univ. California Bull. Dept. Geol. Sci.*, Vol. 18, No. 14 (1929), p. 377.

[62] Harold Ernest Vokes, *op. cit.*, pp. 31, 32, and 36.

[63] Bruce L. Clark, *op. cit.*, p 104.

Domengine Creek, the Domengine is divisible roughly into two units. The lower of these two units is composed of a sand, gray to buff-colored with here and there a purplish cast, fine- to medium-grained with scattered grit, and gritty to pebbly and fossiliferous at base. The upper unit is composed of a silty to clayey shale, green-gray; a few fine-grained sand beds; scattered glauconite grains; abundant Foraminifera and mollusk casts.

The basal pebble bed is fossiliferous for about ½ mile north of the point where it crosses Domengine Creek. From there northward to within ¼ mile of Salt Creek fossils are present in locally well cemented "reefs," 40–60 feet above the basal bed. With the exception of one locality southwest of Ciervo Mountain (Locality W-54) no fossils were observed in the Domengine formation between Salt Creek and Sec. 32, T. 16 S., R. 13 E., on the northeast side of Ciervo Mountain. From this locality to 3 miles north of Panoche Creek, where it is overlapped by the Tulare (Pleistocene), the Domengine is divisible into an upper shale and lower sand that is similar to the section at Oil City. Between Martinez Creek and Arroyo Hondo the Domengine contains several pebble beds. Black chert pebbles are most abundant. White weathering, pink carbonaceous shale pebbles and cobbles are common between Salt Creek and Cantua Creek. Green and red chert, white quartz, and porphyry pebbles are also present. Their size ranges from a grit to a cobble 3 inches in diameter.

At Cantua Creek, beds of pinkish, carbonaceous shales make their appearance and are well developed on the north side of Arroyo Hondo and on the west side of Ciervo Mountain. Locally they contain thin seams of brown lignite. From the Arroyo Hondo to the north side of Ciervo Mountain these shales are interbedded with medium to coarse white sands, with scattered grains of black chert grit that is difficult to separate lithologically from the underlying Yokut.

LITHOLOGIC BOUNDARIES

The lower contact has been discussed in the description of the Yokut and Lodo formations. The "pebble bed" at the base of the Domengine is a remarkably consistent stratum. This bed represents the beginning of a transgression, as it overlaps the Yokut sandstone and Lodo formation to the north and to the south of the Vallecitos structural basin. Although this pebble bed may not have been deposited at exactly the same time throughout its extent, it is thought by the writer to represent the best stratigraphic marker in the area. For this reason the base of the Domengine is used for the datum plane of the section in Figure 1.

In places the Domengine sandstone appears to be a sandy facies at the base of the much thicker Kreyenhagen shale with a gradational contact between the two, and in other places one sees evidence that the contact is an erosional one. From the south end of the Domengine outcrops to Cantua Creek the 6-inch to 4-foot bed of glauconitic sand at the base of the Kreyenhagen rests with a sharp break on the underlying silty shales and sands of the Domengine. However, the only good evidence of a local disconformity between these two formations was noted between Salt Creek and its divide with Martinez Creek. There the Domengine varies in thickness from 165 feet to 22 feet and back to 98 feet within a distance of 2,400 feet. Fossiliferous beds present in the two thicker sections parallel the lower contact of the Domengine and are cut out by the Kreyenhagen shale.

From Martinez Creek northward, the basal part of the Kreyenhagen contains a considerable amount of sand which increases the difficulty of determining the Kreyenhagen-Domengine contact. However, the peculiar "salt and pepper" appearance of these sands makes them distinguishable from the underlying sands of the Domengine. Between Cantua Creek and the north side of Ciervo Mountain this contact was arbitrarily chosen at the base of the lowest brown shales (in most places containing abundant Radiolaria) which overlie the grayish to white-colored sands of the Domengine. The pinkish to brown carbonaceous shales interbedded with the white sands in this region belong to the Domengine, although in color they resemble closely the Kreyenhagen shale.

Between Ciervo Mountain and the north extent of the Domengine outcrops in this region the contact was placed at the base of the lowermost brown shales or "salt and pepper" sands of the Kreyenhagen, depending on which of them overlie the greenish gray, abundantly fossiliferous, silty shales of the Domengine.

Green, "soapy" clay shales are commonly found in the lower 50 feet of the Kreyenhagen. They are interbedded with the typical brown shale of the Kreyenhagen and grade both laterally and vertically into it. They do not represent a cartographic unit.

THICKNESS

The Domengine sandstone varies in thickness. This variability probably is the result of local disconformities and of unequal rates of deposition. The thickness varies from a minimum of 5 feet, a short distance north of Arroyo Hondo, to a maximum of approximately 800 feet on San Carlos Creek.

MINERALOGY

The Domengine sands contain a much larger heavy-mineral suite and a greater percentage of heavy minerals than the underlying Yokut sand. The presence of glaucophane indicates that at least some of the sediments were derived from the Franciscan. Table I shows the great contrast between the mineral suites of the Domengine and Yokut sandstones. A comparison of the sorting between Sample B-1, which was collected at the base of the Domengine in the SW. $\frac{1}{4}$, Sec. 11, T. 16 S., R. 12 E., and Sample I-8, which was collected a few feet above the base of the Domengine in the N. $\frac{1}{2}$, Sec. 21, T. 15 S., R. 12 E., shows the characteristically poor sorting of the basal sands represented in the first sample, while the sorting of the latter sample is equal to that of Sample B-2 from the Yokut sand.

PALEONTOLOGY

The Domengine sandstone contains a well preserved large molluscan fauna which has been described by Dickerson and by Vokes from the southern part of the area herein considered. The northern part of the area from L. S. J. U. Locality 2072, Sec. 10, T. 16 S., R. 12 E., to the north end of the Domengine outcrops contains a fauna analogous to that found farther south. In addition it contains abundant specimens of *Balanophyllia variabilis* Nomland, particularly at L. S. J. U. Locality 2072. In so far as the writer is aware, this coral has not been recorded previously from the Coalinga region.

Although these faunas are marine, Vokes has described a brackish-water fauna from the Domengine in the Vallecitos and the writer has collected some fossils, including *Venericardia carlosensis* (Vokes) and a large *Ostrea* sp., from brown lignitic shales at Locality W-54, Sec. 13, T. 17 S., R. 13 E.

Clark[64] was the first to discover that the fauna of the Domengine sandstone is distinct from the fauna of the Tejon formation. Subsequently he and Vokes[65] appropriated the name for their "Domengine stage."[66]

CONCLUSIONS

An attempt to compare the observed field relationships of the lithogenetic and mappable units of the Eocene north of Coalinga with the existing classifications in the geological literature of the area has dem-

[64] B. L. Clark, *op. cit.*, pp. 99–118.

[65] B. L. Clark and H. E. Vokes, *op. cit.*, pp. 861–63.

[66] Although the fauna of the Domengine formation is distinctive and has been recognized in many parts of California, the writer is not in agreement with the technique of applying formational names to "stages of deposition."

onstrated the necessity for a dual nomenclature in stratigraphic classification—rock-stratigraphic and time-stratigraphic.

It is the purpose of this paper to indicate the necessity for such a dual nomenclature and to present such a rock-stratigraphic classification of the Eocene deposits in the region as will lessen confusion and facilitate the correlation of them with other formations on the basis of a sound time-stratigraphic classification.

Thus, the Yokut sandstone and the Lodo formation are lithogenetic and cartographic units. As such they will remain despite the changing concepts of their ages.

REGISTER OF LOCALITIES

Panoche Quadrangle, Fresno County, California

W-15. 1,000 feet E. along S. line of Sec. 5 from SW. corner, Sec. 5, T. 15 S., R. 12 E. Fossiliferous bed at base of Domengine

I-8. 2,500 feet E., 1,200 feet S. from NW. corner, Sec. 21, T. 15 S., 12 E. Fossils and sand sample locality few feet above base of Domengine

L. S. J. U. 2,072. 2,900 feet E., 1,700 feet S. from NW. corner, Sec. 10, T. 16 S., R. 12 E. Fossiliferous bed at base of Domengine. Abundant *Balanophyllia variabilis*

B-1. 1,200 feet E., 1,200 feet N., SW. corner, Sec. 11, T. 16 S., R. 12 E. Sand sample locality at base of Domengine

B-2. 1,200 feet E., 1,000 feet N., SW. corner, Sec. 11, T. 16 S., R. 12 E. Sand sample locality near middle of Yokut

D-2. 1,800 feet W., 2,100 feet N., SE. corner, Sec. 4, T. 16 S., R. 12 E. Sand sample locality from small sandstone lentil in Lodo in approximately same stratigraphical position as Cantua sandstone

C-2. 300 feet W., 2,000 feet N., SW. corner, Sec. 15, T. 16 S., R. 12 E. Glauconitic sand sample locality at base of Cerros shale

L. S. J. U. 2,073. 250 feet S., N. line, Sec. 29, T. 15 S., R. 12 E., opposite junction of Silver and Panoche creeks in road cut on Panoche Pass Highway. Paleocene molluscan and sand sample locality at base of Lodo

Priest Valley Quadrangle, San Benito and Fresno Counties, California

W-54. 1,400 feet W., 1,600 feet S., NE. corner, Sec. 13, T. 17 S., R. 12 E. *Venericardia carlosensis* in brown lignitic shales of Domengine

W-53. 2,200 feet W., 700 feet N., SE. corner, Sec. 31, T. 16 S., R. 13 E. Fossiliferous "reef" at bottom of small gully at base of white sand in upper part of Yokut

Coalinga Quadrangle, Fresno County, California

U. of C. 1,817. SW. ¼, NW. ¼, Sec. 15, T. 18 S., R. 14 E., 100 feet up fourth small draw from west end of ridge; immediately opposite place where Urruttia Canyon enters Salt Creek. *Turritella andersoni* 50 feet above base of Cerros shale

A-820.* Less than 50 feet below contact with Domengine formation on cliff a few yards north of point where Domengine Creek crosses Yokut outcrop. Fossiliferous bed near top of Lodo

A-821.* In Domengine Canyon, 30–40 feet stratigraphically below locality A-820

A-978.* On north side of Domengine Creek, Sec. 30, T. 19 S., R. 15 E.

Type locality of *Discocyclina clarki* (Cushman)† NE. side Domengine Creek, near corner of SW. ¼, Sec. 29, T. 18 S., R. 15 E., M. D. B. and M., in Lodo formation ("Meganos Group" of B. L. Clark), collector B. L. Clark

* Harold Ernest Vokes, *op. cit.*, p. 188.

† J. A. Cushman, "The American Species of Orthophragmina and Lepidocyclina," *U. S. Geol. Survey Prof. Paper 125D* (1920), p. 42.

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APPLIED PALEONTOLOGY[1]

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ABSTRACT

Paleontology has become an applied science through its usefulness in the interpretation of stratigraphy. The application is based on two laws: (1) superposition of strata, and (2) orderly chronological succession of fossils. Examples show that paleontology is applied commercially in mining and petroleum activities. A graphic analysis of the kinds of fossils which are most useful in the petroleum industry proves that the Foraminifera lead by a wide margin. Finally, the use of fossils is considered as falling into three chief categories of methods: (1) simple matching of assemblages of specimens, (2) the determination of age identity, founded on the principle that all organisms have a limited range in time, and (3) the determination of identity of depositional environment, founded on the principle of uniformitarianism. Since the relationship between paleontology and other means of correlating is an intimate one, the applied paleontologist does not pin his faith entirely on paleontology to the exclusion of other lines of evidence, because, even employing all possible lines of attack, he is often none too certain of his correlations.

BASIS OF APPLIED PALEONTOLOGY

Paleontology has become an applied science through its usefulness in the interpretation of stratigraphy. Many years ago this "writing about strata" became useful to man because so many products are taken from stratified rocks—salt, coal, marble, clay, limestone, and petroleum, to mention a few. The history of the geological sciences does not tell us when fossils were first put to use to aid in extracting these valuable mineral resources from the earth. The application of paleontology to industry came gradually, and only after two fundamental laws had been established: the law of superposition of strata and the law that fossils differ according to their geological ages.

LAW OF SUPERPOSITION

Nicolas Steno (1638–1686) is generally credited with having formulated the first of these laws. Steno (Fig. 1) was born a Dane, but he spent years in Italy at the court of the grand duke of Florence. This was a fortunate circumstance, for it gave him the opportunity to travel and see the geological formations of the Alps and the Apennines. He seems to have been intrigued by the perpendicular and highly inclined strata, and correctly inferred that they were originally horizontal. He

[1] Read, in part, before the Pacific Section, Society of Economic Paleontologists and Mineralogists, March 8, 1940, Los Angeles, California, and in part at the annual meeting of the Society in Chicago, April 12, 1940. Published in the *Bulletin* by permission of the Society.

[2] Box 1528.

further deduced that in any normal sequence of sedimentary formations the upper strata are the younger. This conclusion has come to be known as the "law of superposition"; it is the fundamental law of stratigraphy.

FIG. 1.—Nicolas Steno. Portrait in the Pitti Palace. From Winter (1916).

ORDERLY SUCCESSION OF FOSSILS

A century later (in 1777) the French Abbé Giraud Soulavie stated that formations may be distinguished by their fossils. Doubtless others before him had also remarked that fossils in lower formations are unlike those in higher beds. The significance of this relationship between relative ages of the rocks and the entombed fossils, however, seems to have escaped Soulavie's contemporaries, and it was not until the end of the eighteenth and the beginning of the nineteenth century that other workers began to reach the same conclusion. No one person, in short, can be justly credited with having discovered that fossils differ according to their geological ages.

Thus, applying the law of superposition, a more or less orderly succession of fossils has been worked out through the strata of the earth's crust. This succession accords with the principles of the theory of organic evolution: the older rocks contain less complex fossil organisms than the younger strata. This law of the orderly succession of fossils is the fundamental law of applied paleontology.

STRATA IDENTIFIED BY FOSSILS

Specialists who trace the gradual growth of that branch of science called "stratigraphic geology" are not surprised to find that paleontology was applied long ago to engineering and mining projects. It is surprising that geological historians have not discovered some record showing that it was so applied before William Smith (1769–1838)—an English surveyor (Fig. 2) who is so frequently called the "Father of Stratigraphic Geology."

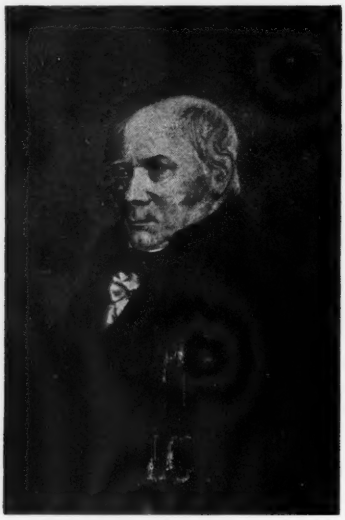

FIG. 2.—William Smith, at the age of 69.
From an engraving by T. A. Dean.

William ("Strata") Smith was a practical man, of humble ancestry and limited schooling. He did not know of the works of Steno, Soulavie, and other predecessors. He had none of the prejudices of the intellectual class of his epoch. He was an unpretentious engineer who had learned something that one can not learn by reading: how to observe facts in the field. Smith was busy as an engineer for six years with the construction of the Somersetshire Coal Canal and his detailed observations of the strata forced him to the realization that "each stratum contained organized fossils peculiar to itself." His work became well known; and finally he received the Wollaston medal of the Geological Society of London in 1831, eight years before his death. This award was for his recording of facts rather than for his philosophy.

So it came about that William Smith received the honor of having first shown the value of fossils in identifying geological formations. His publications were not perfect. His "Strata Identified by Organized Fossils" was woefully incomplete. His technique was imperfect. He had no paleontological knowledge and he spent no time discoursing on which Latin name should be applied to a shell. Many of the pitfalls of stratigraphic geology were unknown to him. Smith's successors have learned that they can make paleontological divisions of great sequences of strata of uniform physical character. They have grasped the importance of changes of facies. But whatever their advances, the generations who follow William Smith may justly call him the "Father of Applied Paleontology," as he was the originator of principles which his successors still use.

UTILITARIAN RÔLE OF PALEONTOLOGY

The practical application of paleontology in all types of work involving stratified sedimentary rocks has been appreciated ever since Smith's day. Numerous examples might be cited of the practical uses to which fossils are put—in quarrying, military operations, tunnelling, archeology, even in criminology. The following examples, limited though they are, should be sufficient for the purpose here.

Paleontology has played and continues to play an exceptionally important utilitarian rôle in the coal industry. Some of the discoveries resulting from applied paleontology read like fiction. A classical one (from Renier, 1908) is that of the "Sondage de Ricard" in France.

The Grand' Combe or Gardon basin, situated on the eastern border of the Cévennes Mountains, had been incompletely exploited. Three groups of productive beds were recognized there. On the one hand, those at Champclauson were stratigraphically above the ones at Trescol, with about 300 meters of sterile deposits separating them. On the other hand, the producing deposits at Ste-Barbe constituted an isolated group of beds separated from the preceding by the highly inclined Malpertus fault. After having made a study of the flora of these beds, Grand 'Eury declared that the Ste-Barbe seams were older than the two others. R. Zeiller in 1880 also studied the flora of the basin and in 1881 he recommended that the mining company should search for the Ste-Barbe deposits below the Trescol ones. Thus, the Ricard boring was begun in 1881. It penetrated to a depth of 400 meters without reaching its objective and the operators began to doubt the paleontologist. Work was stopped in 1882 and a new boring was begun elsewhere in order to explore the foot-wall of the Ste-Barbe beds. But this boring encountered, as might have been foreseen, the Malpertus

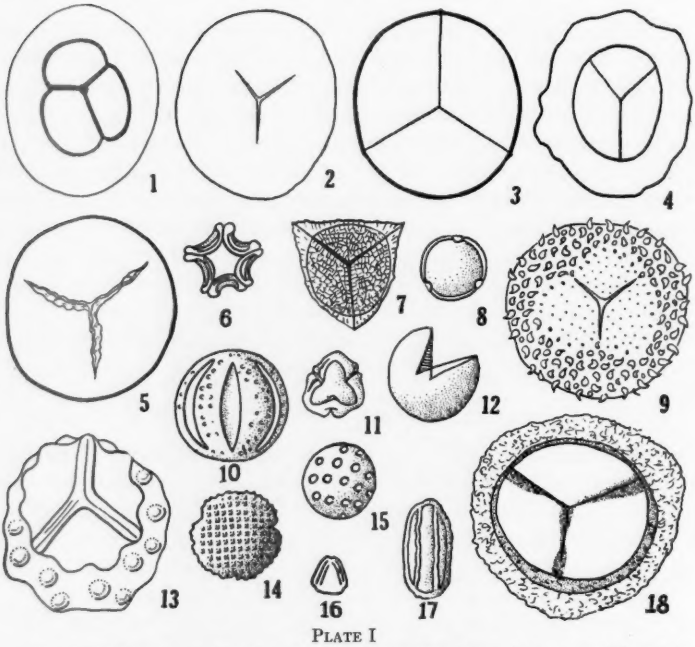

PLATE I

Note: All figures are taken from the following publications which are cited in full in the bibliography: Ibrahim (1933), Potonié (1934), and Sahabi (1936), I-33, P-34, and S-36.

1. One of the smooth spores, or *laevigati* (S-36, p. 35, fig. 4).
2. A second type of smooth spore, *Laevigati-sporites reinschi* (S-36, p. 34, fig. 3).
3. A third type of smooth spore, *Triletes nigrozonalis* (S-36, p. 36, fig. 5).
4. A spore with equatorial ornamentation belonging to the subgroup "*Exosporozonales*" of the "*Zonales*" (S-36, p. 40, fig. 9).
5. A smooth spore resembling the macrospore of the living moss-like lycopod, *Selaginella* (S-36, p. 37, fig. 7).
6. Pollen of the alder, *Alnus* (P-34, p. 6, fig. 28).
7. One of the "*Zonales*," belonging to the subgroup "*Perisporozonales*"; it has also been called *Triletes triangulatus*. Spores of this category do not exceed about 560 microns in size (S-36, p. 43, fig. 11).
8. Pollen with equatorial exitus or germinal aperture (P-34, p. 6, fig. 19).
9. One of the spores with ornamentation over the entire surface—the *Apiculati* group. This one belongs to the subgroup "*Eu-apiculati*." It has also been designated *Triletes tuberculatus*. Spores of this category attain a size of 1,400 microns (S-36, p. 49, fig. 16).
10. Pollen with meridional areas (P-34, p. 6, fig. 14).
11. Pollen with intexine wrinkles. This kind of pollen has an inner and outer wall (P-34, p. 6, fig. 42).
12. Pollen with a furrow, from the cypress, *Taxodium* (P-34, p. 6, fig. 36).
13. One of the spores assigned to the subgroup "*Eu-apiculati*"; *Triletes tuberculatus*. See fig. 9 (S-36, p. 49, fig. 17).
14. Pollen from a composite flower with distinct sculpture (P-34, p. 6, fig. 41).
15. Pollen with many pits from the arrowhead flower, *Sagittaria* (P-34, p. 6, fig. 21).
16. *Pollenites levis*. This fossil may be compared with pollen from *Artocarpus* (P-34, pl. 3, fig. 4).
17. *Pollenites quisqualis*. This pollen is 18 microns long (P-34, pl. 3, fig. 15).
18. *Zonales-sporites saturnoides*. Some classify this spore under the name *Triletes*, a category named by Reinsch in 1881 for all spores with the Y-mark (I-33, pl. 3, fig. 26).

fault. Grand 'Eury was then commissioned by all of the companies to make a general study of the basin. He did so, and reaffirmed the opinion that the Ricard boring had not been deep enough. Convinced, the company resumed the boring and on March 1, 1884, discovered at a depth of 736 and 780 meters two coal seams 5 and 10 meters thick.

Scores of such practical services, made possible by detailed catalogues of coal seams, convinced operators long ago that paleontology is an applied science. Before the turn of this century Leo Cremer and Hans Mentzel established a geological survey under the control and with the financial aid of mine owners in Westphalia. Many private and governmental engineers and paleontologists to-day serve the industry in all coal-mining districts, and the amount of information which they have accumulated is literally breath-taking. Currently, detailed attention is being devoted to microscopic plant spores and pollen, although other fossils continue to be important aids in solving coal-mining problems.

The following freely translated passage from Renier (1908, pp. 5–6) explains, by an apt comparison, how paleontology is employed continually in the coal fields of the world.

> If, from the base to the top of the coal-bearing series, the color of the rocks varied progressively from red to blue, passing through all the shades of the chromatic scale, one might have some hesitation concerning the absolute position of a given bed or thickness of strata which one examines; but his hesitation would be unjustified because he should be guided by a clear-cut and well-defined law.
>
> A healthy, sufficiently trained eye would easily determine the age of the rock, with a rapidity and a certainty which would surely be appreciated. The research would gain even more in exactitude if there are here and there in this stratigraphic scale, as in the solar spectrum, a certain number of dark rays of definite and invariable positions—*horizons* in one word.
>
> Indeed, this comparison applies, in all ways, to paleontological methods. Paleontology is like a spectroscope permitting one to disclose at the same time the existence of a continuous scale and of dark rays across all the series of terrains.
>
> The fossils give to the rock the tint characteristic of its age. From bottom to top of the coal-bearing series each tint varies in a progressive but distinct manner.
>
> On the other hand, across all of the coal-bearing terrain—at least in basins of the Westphalian type—are some fossiliferous horizons which play the part of the dark bands of the solar spectrum and permit one to determine the stratigraphic level, that is to say, the geological horizon of a definite part of the column.

Paleontology aids in determining in detail the sequence of formations in many metal-mining districts. This, as in the coal industry, has practical value. For example, attacks on the problem of the genesis of the Mississippi Valley lead and zinc deposits had to be based on the

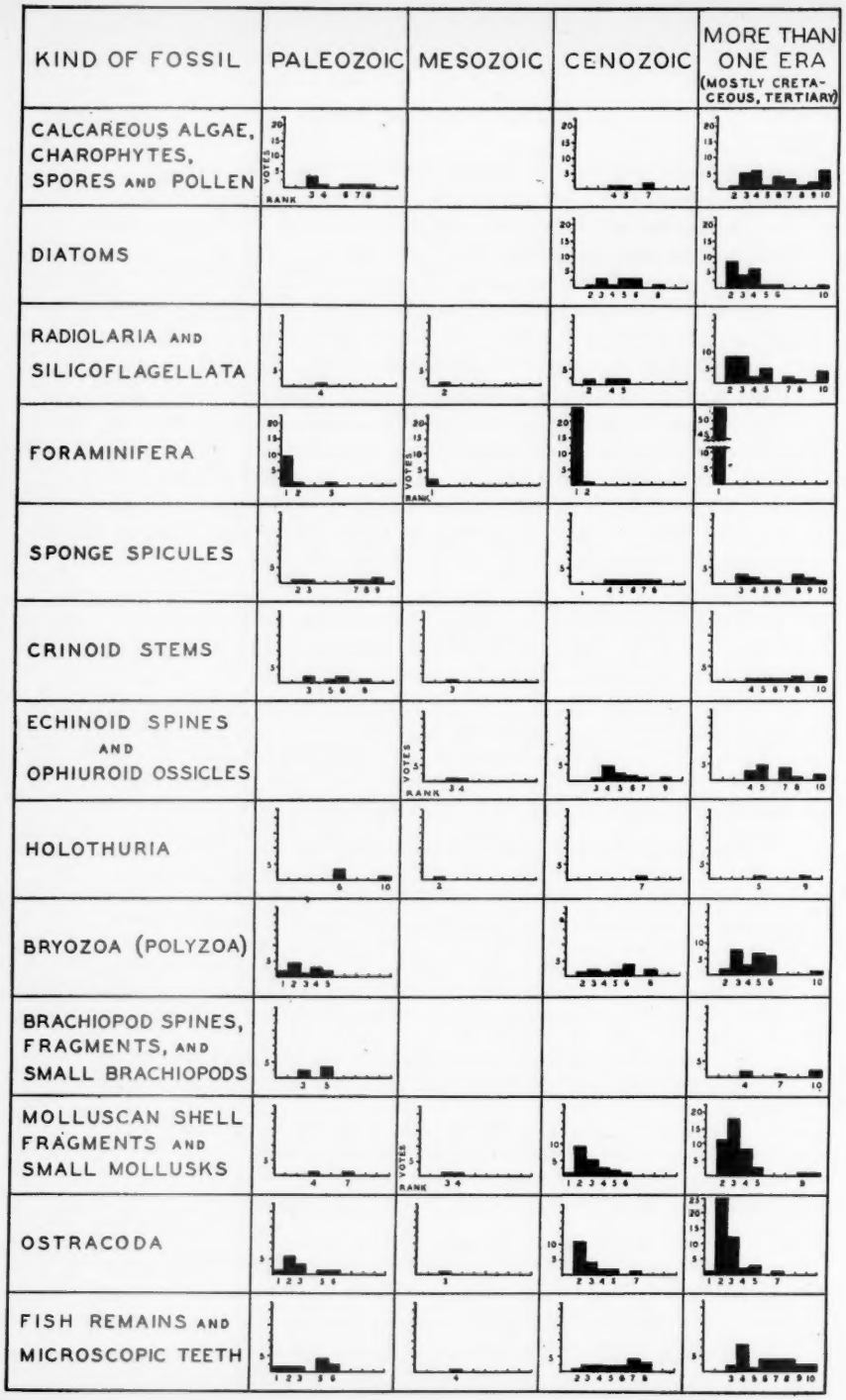

FIG. 3.—Graphic analysis of replies to questionnaire concerning relative importance of microfossils. Chart reads as follows, taking for example Paleozoic Foraminifera rectangle: nine paleontologists voted that the Foraminifera are the most important microfossils for work with Paleozoic formations, one voted that the Foraminifera are second, and one considered that they are fifth.

stratigraphic relations of the ore bodies. Another example is taken from Nevada, as follows.

In the Pioche mining district, Cambrian trilobites have been employed to distinguish between faulted segments of the ore-bearing Pioche shale and the usually unmineralized Chisholm shale.

A determination of the stratigraphic relations of the Cambrian Highland Peak limestone in one area of the same district provided data necessary to ascertain the previously unknown stratigraphic position of the Bristol Silver Mine workings, 20 miles distant. With this information, a winze was sunk from the lowest workings (1,500-foot level) in search of a known potential ore-bearing limestone, which, when encountered on the 1,700-foot level, constituted an excellent ore body.

The most important economic application of paleontology to-day is in the petroleum industry, due to the special need of accurately identifying strata and the particular difficulties involved in doing so at great depths below the surface of the ground. Oil companies began to organize paleontological laboratories about 1921 and the demands for paleontologists increased yearly thereafter. In March, 1927, a meeting was held in Texas to organize the Society of Economic Paleontologists and Mineralogists. This organization in March, 1940, had on its roster 318 modern William Smiths most of whom are employed by oil companies. In California alone the professional paleontologists and their helpers total nearly 100 in number and more than 120,000 samples are examined annually. The cost of equipping a modern laboratory for 10 men may be estimated at $20,000. Several laboratories of this size and many less elaborate commercial ones are operating daily not only in California but also in the Gulf Coast, Europe, Iraq, Netherlands East Indies, Cuba, South America, and elsewhere. It is estimated that more than one million dollars is being spent each year on the operation of these oil-company laboratories.

ECONOMICALLY IMPORTANT MICROFOSSILS

In order to determine what kinds of fossils are most useful in industry, a questionnaire was sent to 166 paleontologists. They were requested to rate, in order of importance, the principal categories of microfossils. The word importance was to be construed as the value of those microfossils used in routine work as indicators of environment and chronology. The results of this inquiry are given in Figure 3, an analysis of 101 replies covering the following areas: twenty-four states of the United States; Alaska; Canada; Mexico; Central America; the West Indies; five countries in South America; Netherlands East

Indies; Philippine Islands; New Zealand; Papua; British Borneo; seven countries in Europe; the Near and Middle East; northern and western Africa; British India; and Burma. The Foraminifera are most important by all counts. Second place is held by the Ostracoda, although some workers dealing with Cenozoic strata consider the Mollusca more valuable and others use diatoms more frequently. Third place is best given to the Mollusca, despite the low rating by those voters who are concerned only with Paleozoic fossils. In many districts, microscopic teeth are more useful than all other kinds of fossils. The Bryozoa fall in fourth place, but here again the rank depends on the ages of the formations, since by and large for Paleozoic correlations the bryozoans rank third. The other categories are relatively less important in the petroleum industry except in special cases.

PROVED CHRONOLOGICAL VALUE OF MICROFOSSILS

The present-day oil-field specialists have learned that the most widespread application of paleontology is in the dating of strata by tying them to a certain epoch of geological time through the position of their fossils in the evolutionary sequence of life forms. Many fossils thus become reliable geological time-markers because like the individuals which compose them species have a limited existence in time. Even beginning students in geology know that a limestone with fusulinid foraminifers is a rock of late Paleozoic age, as these fossils have been found in hundreds of localities only in beds younger than Devonian and older than Triassic. The nummulites are so widely distributed in Eocene and Oligocene formations that the well known French savant, E. Haug (1861–1927), called the period of their flourishing the *Nummulitique*. This categorical statement is warranted: the determination of the relative ages of geological formations by the aid of small fossils is not a matter of speculation; it is a matter of fact, tested and proved time after time.

ECOLOGICAL VALUE OF MICROFOSSILS

Gradually also came the realization that fossils are valuable as indicators of ancient environments because of the truth of the formula that "The Present is the Key to the Past." A study of the distribution of Recent organisms shows that certain ones have definite habitats, and even those forms that are distributed throughout the world to-day live only under certain conditions. Each species lives in its own ecologic niche and some naturalists will go so far as to say, "Name the organism and I will tell you its habitat."

The following example explains why those interested in the geo-

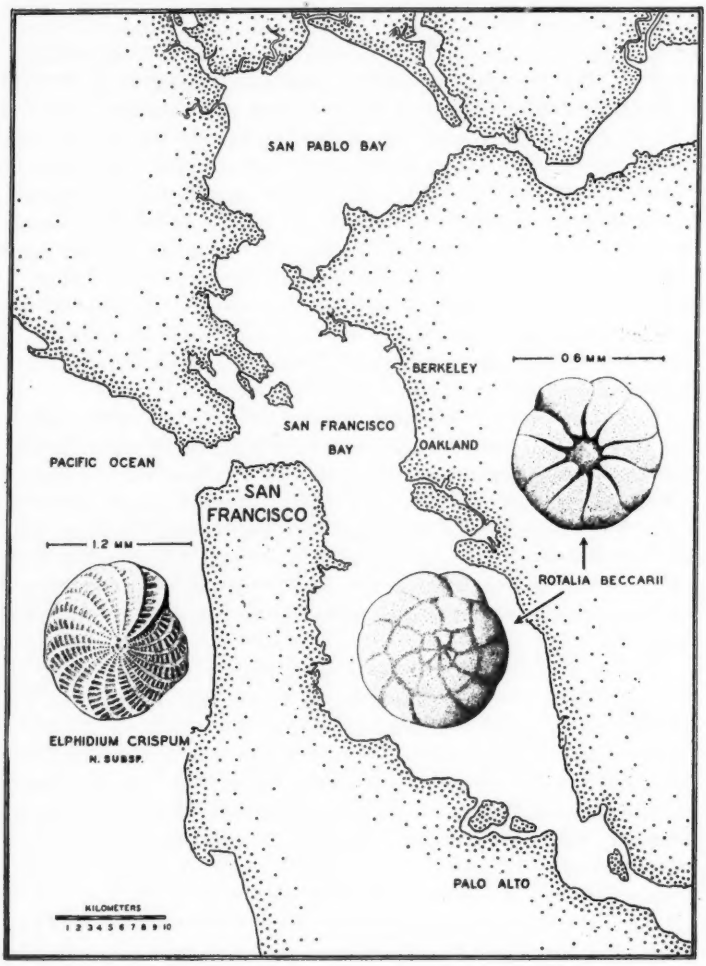

FIG. 4.—Map of San Francisco Bay region, California. *Rotalia beccarii* (Linné) is common in shore sands of bay, whereas *Elphidium crispum* (Linné), new subspecies, is abundant in littoral zone of open-ocean coast.

graphic distribution of organisms know that there is an intimate relation between living beings and their environments.

For a number of years collectors have been gathering at low tide mollusks, foraminifers, and other invertebrate animals from the shores of the Pacific Ocean and San Francisco Bay south of San Francisco (Fig. 4). The peninsula separating these two environments is only 9 or 10 miles wide. The mollusks from the two localities comprise recognizably different assemblages and the same holds true for the foraminifers and other invertebrates. For instance, the shore sands of San Francisco Bay abound in specimens of *Rotalia beccarii* (Linné). This species has not been found in the samples from the littoral zone of the open-ocean coast. Similarly, numerous foraminifers in the open coast collections are never found in the bay. Without further elaboration, one can thus make this assertion: if a specialist is given an unlabelled assemblage, he can say whether it comes from a brackish-water bay or from the open ocean, much as an expert fisherman can tell whether a fish comes from fresh or salt water.

The optimum development of *Rotalia beccarii* in brackish water is not restricted to central California. Collections from other bays of western North America include this species. The same may be said for the coasts of Louisiana and Texas. In the brackish "lake" of Maracaibo, Venezuela, lives an association like that of San Francisco Bay, with *Rotalia beccarii*, *Quinqueloculina fusca*, and other smaller foraminifers. One may thus conclude that an abundance of specimens properly identified as *Rotalia beccarii* suggests shallow, brackish waters.[3]

This principle—that of telling past conditions by comparisons with the present—is not new. Leonardo da Vinci (1452–1519), who, like William Smith, was a level-headed, practical man, knew and applied it to the fossils he saw in Italy. Anyone knows that a rock containing palm leaves was not formed under arctic conditions. One also knows that the more accurate deductions are obtainable when the fossils are from the younger formations, because fossil organisms that have close relatives among living species are subject to more direct analysis than those fossils which belong to species long extinct.

The subject of ecology has such a direct bearing on the many aspects of stratigraphic geology that much attention is given to it by commercial geologists. The similarity of specimens from different localities may be due to the fact that the animals lived in similar en-

[3] Here, as elsewhere, the reader will not accept a broad statement without qualifications. For example, he may know that *Rotalia beccarii* in the Adriatic Sea is associated with *Elphidium crispum* (of authors). The association of these two species, however, does not invalidate the foregoing generalization.

vironments rather than during the same geological epoch. There, in a nut shell, is the bearing of ecology on the synchronization of geological formations.

OBJECTIVE OF APPLIED PALEONTOLOGY

The main objective of applied paleontology to-day is the identification and correlation of strata. Geologists do not always appreciate the important and real distinction between local and interregional synchronizations of strata. Local correlations are relatively simple; interregional ones involve a consideration of a multitude of different and variable factors. A correlation from one oil well in a given basin to another in the same basin is not the same as synchronizing a certain formation in California with one in Europe. An engineer standing beside an oil well on Kettleman Hills, California, can look to the west and see exposed the strata encountered in the well, and with the aid of lithology and fossils he can correlate from well to outcrop. Such a correlation is comparable to matching samples of ribbon for color. In contrast, an attempt to match this Californian stratigraphic sequence with that in Europe—the geological holy land of so many geologists—is complicated by scores of problems.

The distinction between broad-scale and small-scale correlations is likewise a real one. To date a formation as late Paleozoic can be done by a novice if he has well preserved fossils. To date a given fossiliferous stratum as late early Permian, as late Middle Devonian, or as early middle Pennsylvanian should be attempted only by a specialist, and he sometimes may have misgivings, for ecology and a score of other factors must be considered. Breadth of training and professional experience give one a knowledge of limits of accuracy.

The paleontologist who is primarily seeking immediate practical results in local geological correlation can pass over many of the problems which would demand the attention of the more philosophically inclined scientist. The economic paleontologist can use fossils without intimate knowledge of every phylum of the animal and plant kingdoms or without being an authority on even any one phylum. For well-to-well or well-to-outcrop correlations the oil-field paleontologist can "match samples" within limits and let zoölogists and paleobiologists deal with the question of what constitutes a species. William Smith, the practical engineer, recognized distinctive fossils from the Mesozoic beds of England without arguing about what name he should apply to each specimen. The important requirement is that the specimens must be painstakingly discriminated. Identify with care and correlate with caution is a commandment directed at every scientist, not excluding the paleontologist.

METHODS OF CORRELATION

Training and experience teach the necessary scientific judgment and caution in the intelligent use of fossils. Workers in one region become skilled in the separation of Paleozoic species which might all look alike to the worker dealing only with Tertiary fossils. Yet whatever the kind and age of the groups of fossils, their use in the correlation of strata is by three chief categories of methods: (1) simple matching of assemblages of specimens, (2) determination of age identity, and (3) determination of identity of depositional environment.

CORRELATION BY MATCHING ASSEMBLAGES

The simplest and a common type of correlation is by matching assemblages to determine the species in common between two or more samples. For example, the paleontologist may have a sequence of assemblages of foraminifers from a completely sampled section. "A" is a collection from the lowest stratum; "B" is a collection from 10 feet higher; "C" is from 10 feet above "B," and so on. Another sequence of assemblages from another carefully sampled section is compared with the first. "X," the lowest stratigraphically, is compared with "A"; collection "Y," from 10 feet above "X," is compared with "B," and so on. If the two sequences match exactly both in order of stratigraphic occurrence and in faunal composition the paleontologist feels justified in believing that the assemblages are of the same geological age. This type of correlation may be carried out without any idea of the precise geological age of the strata or of the conditions of their deposition.

Such a correlation by "matching" has its counterpart in correlations based on lithology without fossils. The top of a shale in one well, for example, is correlated with the top of a shale in another well. Some remarkably accurate correlations have resulted from carefully comparing electrical well logs. That matching of distinctive lithologies has often yielded satisfactory results is well known. The hazards of these correlations are nevertheless many; fossils must be used like police in order to keep straggling strata within limits.

CORRELATION BY AGE IDENTITY

Correlation through age identity is based on the demonstrated fact that many fossils are valuable time-pieces. The following are examples of this method of applying paleontology to the correlation of strata by age identity.

A company was drilling a wildcat well in an area in South America far from any proved oil production. The geologist had recommended

the test in the hope that oil sands would be discovered in a certain Jurassic formation. The drill passed through Tertiary strata, which were readily identified by *Lepidocyclina* (Pl. II, Fig. 1) and other foraminifers, into a dark limestone which the geologist believed to be

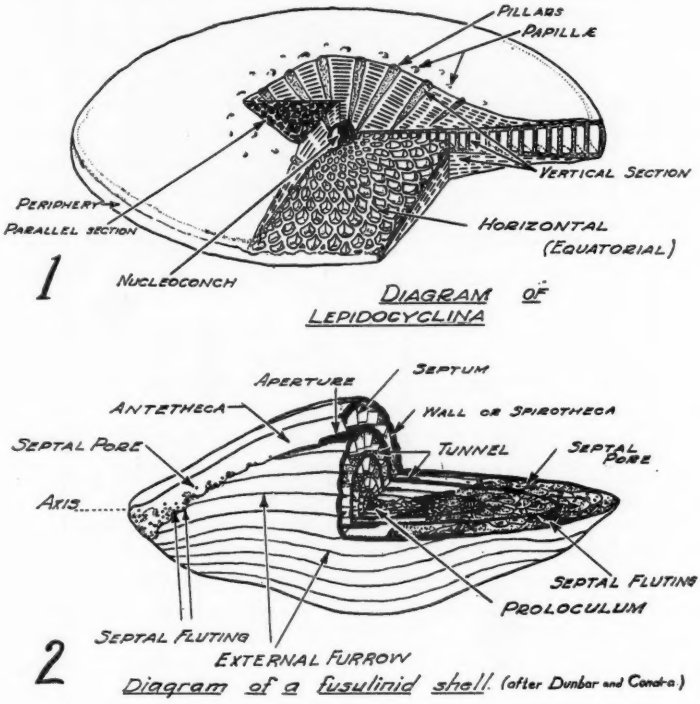

PLATE II

FIG. 1.—Generalized diagram of *Lepidocyclina, sensu stricto*, after Schenck and Aguerrevere (1926). This subgenus ranges from medial Eocene through Oligocene and questionably into early Miocene. Closely related subgenera have longer range: from early Eocene to late Miocene. These foraminifers, few of which exceed a diameter of 3 inches, are cosmopolitan in distribution.

FIG. 2.—Diagram of a fusulinid foraminifer, after Dunbar and Condra (1927). Members of family Fusulinidae range from early Pennsylvanian (Moscovian) to late Permian time. Reported occurrences in rocks of Mississippian (Dinantian) age need verification. The largest fusulines are rarely longer than 3 inches.

of Cretaceous age. However, when the core samples were submitted to the paleontologist he found that the limestone contained numerous specimens of fusulinid foraminifers (Pl. II, Fig. 2). Since the fusulines

are unknown in rocks younger than Permian, it was evident that the Jurassic formation, in which oil had been expected, was not present. This discovery showed that deeper drilling at that locality would be a waste of money and the well was accordingly abandoned soon after-

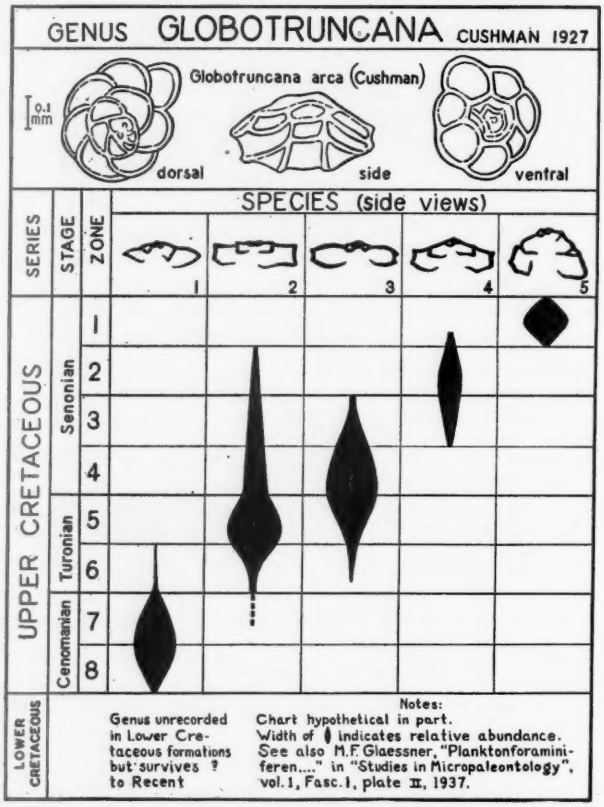

FIG. 5.—Stratigraphic distribution (hypothetical in part) of *Globotruncana*. Thalmann, after careful investigation, holds that this genus of smaller foraminifers is restricted to Upper Cretaceous rocks, believing that the Recent records are in error. Palmer (1940) has found specimens of *Globotruncana* in an Oligocene formation in Cuba. Observe the differences in profiles of the several species.

ward. The company officials here acted on their confidence in the ability of the paleontologist to use fossils as geological time-pieces.

Figure 5, giving the distribution of some species of the foraminiferal genus *Globotruncana*, is designed to illustrate how fossils may be

employed for small-scale correlations or zonation of the geological column. The side views of the specimens illustrate how minute differences of form must be recognized in the separation of species, and that when thus finely divided the species are restricted in distribution. Two out of several methods of using the small foraminifers may be mentioned.

One method is that of "picking tops" or "horizons of extinction." For example, suppose that a well is being drilled in Texas. A sample from a depth of 2,000 feet yields the first occurrence of numerous specimens of the species shown on the extreme right of the chart. It may be called *Globotruncana* species 5. At a depth of 2,500 feet the samples contain species 5 and the one at the left of it on the diagram, that is, species 4, or *Globotruncana arca;* it is not found in higher beds. Samples from a depth of 3,000 feet have specimens of species 2. A similar sequence of "tops" in another well would be used in correlation. This practice of correlation by "picking tops" has been successful where there is a uniform sequence of "horizons of extinction" and a number of distinctive lithologic units.

Another way to use fossils as age indicators is illustrated by Figure 5—by the establishment of faunal zones which are independent of lithology. Notice that *Globotruncana* species 5 is restricted to Zone 1. Species 4 is not so restricted, ranging as it does from the bottom of Zone 3. Species 1 (left-hand column) is rare in Zone 6, abundant in Zones 7 and 8. Species 2 is rare in Zone 6, plentiful in Zone 5, and fairly common in Zones 3 and 4, petering out in Zone 2. Species 3 of the chart is present in Zone 3, abundant in Zones 4 and 5, and does not occur below Zone 6. Only species 5 is restricted to a single zone, where there is a "flood" of specimens. Zones 2, 4, and 5 can not be established by species of the single genus *Globotruncana;* other fossils must be drafted into service. Zone 3 could be based on the mutual association of *Globotruncana* species 2, 3, and 4 for the reason that in no other part of the geological column do these three species occur together. Relative abundance might be used as a tentative basis for zonation in a well explored region, but there are many pitfalls awaiting the relative-abundance addict, no matter how thorough a grasp he may have of statistical methods. Zone 6 is established by the association of species 1, 2, and 3, because, as with Zone 3, this permutation of combinations is unique. If species 3 is absent, one could postulate that the sample comes from the base of Zone 6, but absence of specimens is another dangerous criterion. Zones 7 and 8 could not be set up with this *Globotruncana* scale.

Such a zonation as this can not be established on the basis of speci-

mens of one genus from one well or from one surface section. Reliable stratigraphic zonation is possible only after several sections have been

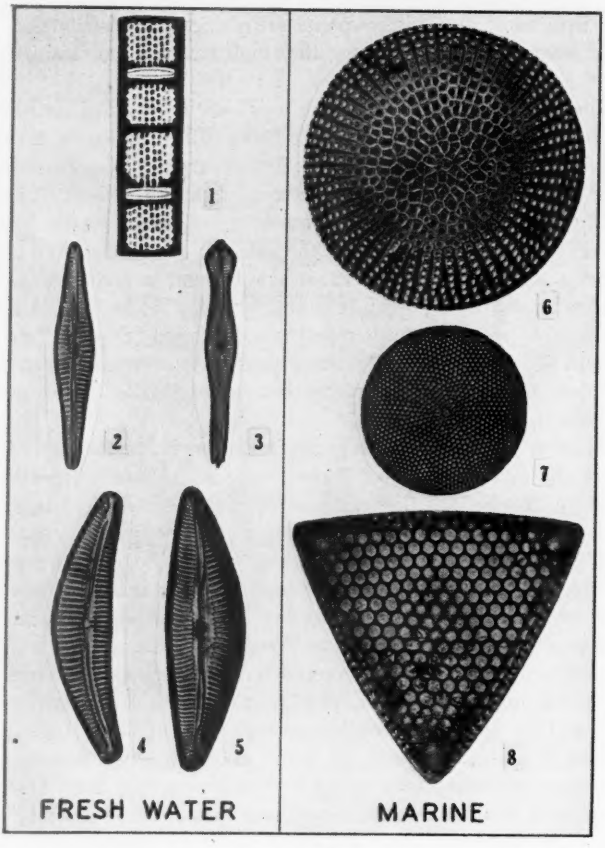

PLATE III

Note: The figures on this plate are from Hanna (1932), Hanna and Grant (1926), Lohman (1938), and Reinhold (1937).

1. *Melosira granulata* (Ehrenberg) Ralfs. Tulare formation (upper Cenozoic) of California. Length of the two frustules, 0.047 mm.; diameter, 0.013 mm.
2. *Gomphonema semiapertum* Grunow. Pliocene, Kansas. Length, 0.0562 mm.
3. *Gomphonema acuminatum* Ehrenberg. Pliocene, Kansas. Length, 0.0563 mm.
4. *Cymbella parva* Smith. Pliocene, Kansas. Length, 0.0516 mm.
5. *Cymbella aspera* (Ehrenberg). Pliocene, Kansas. Length, 0.0546 mm.
6. *Stictodiscus californicus* var. *nankoorensis* Grunow. Miocene, Java. Diameter 0.12 mm.
7. *Coscinodiscus curvatulus* Grunow. Miocene, Mexico. Diameter, 0.0658 mm.
8. *Triceratium favus* Ehrenberg var. Neogene, Java. Diameter, 0.125 mm.

closely and accurately sampled, meticulously studied, accurately correlated, and the correlations tested. Even then the paleontologist bears in mind that since the total stratigraphic ranges of characteristic fossils is frequently based on negative evidence (absence above or below certain strata), such zones will become more and more precisely delimited as more sections are sampled and studied and as the mutual occurrences of many species are established beyond question.

CORRELATION BY ENVIRONMENT IDENTITY

The third chief method of correlation of strata is through identity of depositional environment. The following is an example.

A number of test wells were being drilled a few years ago in the San Joaquin Valley, California, in a part of that wide plain where alluvium is thick. In order to determine whether the geological structure was favorable or not, the operating concern wished to find the same stratum or strata in several wells. So each was cored from top to bottom. The core samples of the first boring showed sand, gravel, and clay for more than 1,000 feet below the surface; then came a brown shale several feet thick; next 100 feet or so of sandstone, succeeded downward by another brown shale. The remainder of the drilling was in sandstone. Three other test holes showed the same succession of beds with one notable exception—only one brown shale was present in wells No. 2, 3, and 4. The problem before the operator was, of course, this: did the brown shales in well No. 1 represent two different formations or only one formation which had been repeated by faulting or overturning? If two different shale formations were present, which of them should be correlated with the brown shale in the other three wells?

This problem was solved by the paleontologist. The upper shale in well No. 1 proved to be a diatomaceous shale which had been deposited in fresh water. *Melosira granulata* (Pl. III, Fig. 1) was the dominant diatom species in the shale; in fact, practically no other species were present. The lower brown shale in well No. 1 and the brown shale in wells No. 2, 3, and 4 were also diatomaceous, but they were laid down in marine waters, the dominant diatoms being a species of *Triceratium* and several species of *Coscinodiscus* (Pl. III, Figs. 7 and 8). The shale formations in well No. 1, therefore, were not the same, and the lower one had not been repeated due to structural complications. Only after this decision had been reached was it possible to work out the structure. This discrimination of strata was due to the ability of the paleontologist to distinguish between fresh-water and marine diatoms.

CORRELATIONS NOT EMPIRICAL

The correlation of strata should not be empirical. Recurrence of similar facies during geological time is common and consequently similar or even identical fossils may occur more than once in the geological column. The graptolite *Dictyonema* occurs in abundance at the base of the Tremadoc beds in the British Isles, and this fossil has been taken as fixing a definite horizon. Unfortunately for the empiricist, said Davies (1938), in North Wales this facies is repeated, so that there are two *Dictyonema* beds separated by 500 feet of strata. One European stratigrapher has presented evidence to prove that the shallow-water upper Oligocene sands of Germany change laterally into the typical middle Oligocene clay—a deeper-water deposit—suggesting thereby that the divisions of the Oligocene were not justified, because where facies are similar the faunas are alike. Then, too, the paleontologist knows that some organisms endure for long periods of time, locally flourishing, then declining, and then during another epoch they flourish again. He also knows that some supposed evolutionary series, presumedly from simple to complex, may be deceptive, and he appreciates the fact that similar ornamentations on shells are frequently repeated in different lineages. Misplaced confidence in the stratigraphic positions of fossils and the overlooking of unconformities have caused mistakes. Such matters, therefore, justify a cautious approach to problems of geological correlation.

CONCLUSION

The preceding discussion has shown that paleontology can be applied to industry because of the acceptance of certain fundamental principles, that the main objective of applied paleontology is the identification and synchronization of strata, and that there are three main categories of methods of reaching this objective. Degree of success is measured by accurate correlations. In view of the many pitfalls and difficulties attendant on paleontological correlation, the paleontologist must be able to supplement fossils by the use of lithology, mineralogy, electrical logs, stratigraphic intervals, and such other criteria as may be available to him. The relationship between paleontology and other means of correlating, therefore, is an intimate one. The applied paleontologist does not pin his faith entirely on paleontology to the exclusion of other lines of evidence, because even employing all possible lines of attack he is often none too certain of his correlations.

In conclusion, the writer wishes to express his sincere appreciation of the many helpful suggestions from Bradford C. Adams, Hollis D. Hedberg, A. Myra Keen, Malcomb B. Kildale, Boris Laiming, William

A. Newton, Philip W. Reinhart, W. Egbert Schenck, C. F. Tolman and Robert T. White. He is indebted to the many paleontologists whose replies to his questionnaire were used in making the graphic analysis of economically important microfossils. The statement concerning the Pioche mining district was supplied by Harry E. Wheeler. The portrait of William Smith is reproduced with the permission of the authorities of the British Museum (Natural History). Dorothy Kemper Palmer kindly wrote concerning the Oligocene occurrences of *Globotruncana* and sent material for examination. Mrs. Carl F. Janish prepared the originals of Plate I, of Figure 4, and of Figure 5. Conversations with Armand Renier, in Brussels and Liége, the examination of some of his large supply of specimens and geological columns, and the reading of his many contributions have given the writer a greater realization of the value of paleontology to the coal-mining industry and of the services which he has rendered it personally. The writer knows very well that he can not possibly discuss adequately the many aspects of applied paleontology in such a short article as this, and anticipating that some readers may wish to pursue further the ideas sketched here, he has prepared the accompanying bibliographic references with the aid of Le Vern Cutler. Many of these have been used during the preparation of this essay, but for the sake of style the statements are not documented.

Papers dealing with the practical use of fossils are legion; among them are those by Barker, Camp and Hanna, Chapman, Cushman, de Launay, Delépine, Elles, Franke, Hanna (1924, 1926), Hanna and Driver, Hecht, Hedberg (1928), Hensen, Hensoldt, Herold, Hutcheson, Jongmans, Kidston, King, Lacoste, Luber and Waltz, Lull, Marie, Mills, Milner, Myers, Nuttall, Pontonié (1934, 1935), Raistrick and Simpson, Reed, Renier (1905, 1908), Richter, Roberts, Scheffen, Schenck (1938), Schenck, Keen and Martin (1940), Schuchert, Thalmann (1938), Tolman, Tromp, Vlerk, Wedekind, Wetzel, and Wichter. The applied paleontologist wishing to acquire a historical background for the field of stratigraphic paleontology may desire to read F. D. Adams, d'Archiac, d'Orbigny, Dumont, Agar, Flint and Longwell (1929), Geikie, Grabau, Marcou, Mather and Mason, Merrill, H. Potonié (pp. 348–61), Williams, Winter, Woodford, Woodward, and Zittel. Collateral reading on the subject of ecology and facies might begin with Caster, Davies, Hedberg, Hesse *et al.*, Howarth, Kleinpell, Natland, Neaverson, Norton, Nuttall, Packard, Scott, Vaughan, and Woolnough. Papers dealing with correlations by lithology, electrical logs, and other inorganic criteria are by J. E. Adams, Cartwright, Charrin, Goldman, Gillingham, Goudkoff, Leonardon,

Reed, Schlumberger and Leonardon, Tyler, and others. Study groups selecting evolution as a general topic may place on their reading lists such references as the following: Crampton, Dampier, Davidaschvili, Goldschmidt, Kellogg, Lull, Matthew, Morgan, Newman, Nordenskiöld, Osborn, Scott, Smith (1897), Taylor, Swinnerton, and Williston. The stimulating classic by Renier (1908) contains a discussion of paleontological methods which micropaleontologists will find particularly fascinating. Finally, the paleontologist concerned with the establishment of *Zones* will doubtless consult the following references: B. C. Adams, Arkell, Davies (1930), Diener, Heim, Kidston, Kleinpell, Murray and Hjort, Neaverson, Pia, Schenck (1939), Smith (1900), and Weir and Leitch.

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VOL. 24, NO. 10 (OCTOBER, 1940), PP. 1779-1797, 5 FIGS.

LARGER GAS FIELDS IN KANSAS[1]

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Wichita, Kansas

ABSTRACT

A brief history of the Kansas natural-gas industry is given. Present status of the old shallow producing area of eastern Kansas is presented and a structure map of a typical Bartlesville sand pool is shown. The principal gas pools of the western part of the state are described individually and history, completion practice, structure, quality of the gas, pipe-line outlets, State proration of certain pools, and other data are summarized. Structure maps of several pools contoured on the producing formations are presented. A list of the various gas-producing "sands" is given and reserves of some of the principal fields are estimated.

INTRODUCTION

The production and sale of natural gas has been one of the major industries of Kansas for the past 50 years. Commercial production was first developed in Miami County in the year 1860 and the availability of plentiful supplies of natural gas at shallow depths gave rise to the rapid development of eastern Kansas into the principal industrial area of the state. The tremendous demand created by smelters, cement and brick plants, and lesser industries eventually depleted the eastern fields so that it is now necessary to import gas fuel from other areas to supply these markets.

EASTERN KANSAS

It is impossible to ascertain just how many gas wells have been drilled in eastern Kansas, which comprises about one-third of the area of the state. The number is undoubtedly more than 15,000 and probably is nearer 25,000. Depths of wells vary from less than 100 feet to approximately 2,000 feet, most of them being between 800 and 1,000 feet deep. Gas is found in sand, limestone, shale, coal, and chert, but the principal producing formation has been the Bartlesville sand which occurs in lenticular form in the Cherokee shale.

PIQUA POOL

The Piqua gas pool of western Allen County and eastern Woodson County is a typical Bartlesville sand pool. Figure 1 shows the nature of the producing structure. This pool was discovered in December, 1922, the discovery well being located on a surface structure mapped on the Stanton limestone. The anticlinal producing structure does not

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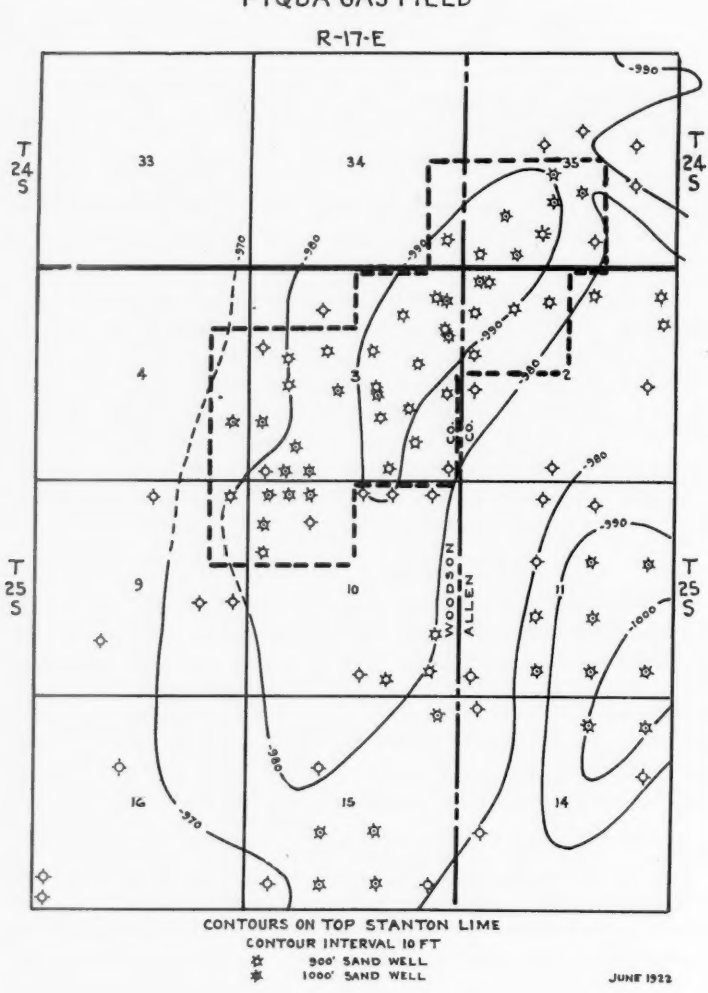

PIQUA GAS FIELD
R-17-E
T 24 S
T 25 S
33
34
35
4
3
2
9
10
11
16
15
14
-970
-980
-990
-1000
WOODSON CO.
ALLEN CO.
CONTOURS ON TOP STANTON LIME
CONTOUR INTERVAL 10 FT
900' SAND WELL
1000' SAND WELL
JUNE 1922

FIG. 1

appear to exist in beds below the base of the Pennsylvanian system and it is assumed that the apparent folding is caused by differential settling or compaction of the Cherokee shale over and around the two producing sand bodies which occur within this shale. The two sands are locally called the upper and lower Bartlesville and are separated by 100–125 feet of shale. Initial open-flow volumes of individual wells ranged from 500,000 cubic feet to 12 million cubic feet and shut-in initial pressures were 295 pounds gauge on the upper, and 320 pounds on the lower, sand. The pool has produced approximately 4,500 million cubic feet to date and several wells still are producing. The productive area comprises approximately 880 acres, although neither sand produces over all the area.

All wells in this pool were drilled with machines and completion practice was as follows. A 10-inch hole was commenced and 10–40 feet of 10-inch drive pipe set; 8-inch casing was set at about 700 feet and $6\frac{1}{4}$-inch set above the upper sand; if the well was drilled to the lower sand and gas was encountered in the upper, the $6\frac{1}{4}$-inch was set through the first sand and the gas flow was killed; $4\frac{7}{8}$-inch casing was set immediately above the lower sand. After the well was drilled in, the $8\frac{1}{4}$-inch pipe was pulled and if the well was small in size, a string of 2-inch tubing was run with packer set immediately below the producing string seat at the top of the sand, and all pipe except drive pipe was pulled. This has been the standard completion practice in eastern Kansas in nearly all pools.

No figure is available covering the total gas production to date of eastern Kansas, nor is it possible to make anything better than a guess about the reserves of the area. A new well, recently drilled in Jefferson County, in the southern part of the Forest City basin, is reported to have encountered 8 or 9 million cubic feet open-flow in the Bartlesville sand, but as no other wells have been completed near it, no estimate of the gas reserve is possible as yet. There is considerable drilling activity at all times in southeast Kansas but nearly all new wells are small in size. Collectively, however, they are capable of producing a substantial amount of gas and owing to their proximity to markets undoubtedly this activity will continue. A rough estimate of the reserves of eastern Kansas would be 100 billion cubic feet although this may be proved very much in error, especially if additional pools are found in the Forest City basin.

WESTERN KANSAS

The principal gas reserves of Kansas now lie within the western part of the state. The first gas well reported in this area was completed

in the year 1888 near the town of Lyons in Rice County. No other gas development was recorded, however, for many years, and practically all of the present fields have been drilled within the past 12 years. In considering these present gas fields and the reserves of this area it appears best to describe them separately, and a brief summary of the history, development, and completion practice of each is given, together with an estimate of the present reserves. Various data on all pools are shown in tabulated form.

HUGOTON FIELD

So much has been written concerning this field that nearly everyone interested in the gas industry is more or less familiar with it. The discovery gas well was completed in December, 1922, by the Defenders and Traders Oil Company on the Boles lease in Sec. 3, T. 35 S., R. 34 W., Seward County. Four more gas wells were drilled in the immediate vicinity of this well but it was not until November, 1927, that the Stevens County producing area was proved by the drill. The discovery well here was the W. M. McKnab and Independent Oil and Gas Company's Crawford No. 1, in Sec. 31, T. 33 S., R. 37 W. Major development occurred in 1930 when the first pipe-line outlet to the field was provided, and as other lines were constructed additional wells were drilled, so that by January 1, 1940, there were 282 wells completed. These wells are in seven counties: Morton, Stevens, Seward, Grant, Haskell, Kearney, and Finney. There are also 13 wells in the developed part which extends into Texas County, Oklahoma. Seven pipe lines provide a market outlet for the gas, these lines belonging to the Argus Natural Gas Company, the Central Gas Utilities Company, the Columbian Carbon Company, the Liberal Gas Company, the Northern Natural Gas Company, the Panhandle Eastern Pipe Line Company, the Tri-County Gas Company, and the United Producing Company. Gas is transported to points as far distant as Detroit and Minneapolis and major pipe lines from the field to other markets are under consideration at the present time.

Since other reports have been published describing the geology of the field it will be summarized only briefly here. The gas occurs in porous zones encountered in beds of dolomite and limestone some of which contain chert. These beds are found in the Sumner and Chase groups of the Permian system. Since there is a scarcity of source material deemed necessary for the formation of natural gas within the formations of these groups, it appears probable that the gas originated elsewhere and migrated into its present reservoirs. Source beds are present in the Anadarko basin on the southeast and the gas may have

its source there. It is possible that it originated in beds much older than those in which it is now found as older beds are in contact with buried mountains on the south in the Panhandle of Texas and these buried mountains are in contact with the Hugoton field producing formations, which are thought to have at least some continuity across the intervening area. The field seems to be limited on the east and west by changes in lithologic character of the reservoir formations, which grade into redbeds of low permeability in both these directions. The northern limit of the field has not been determined as yet, nor have definite boundaries been established in any direction, and no dry holes have been drilled within the present field limits. The regional structure consists of an eastward-dipping homocline with an average dip of about 16 feet per mile. The gas probably migrated into the porous zones where it is now encountered, and it was confined there because of the impervious beds surrounding the reservoir. No edge or bottom water has been encountered in the producing formations and no water drive appears to be present. Gas is found in five different porous zones and these have greatly different permeabilities and porosities, causing large differences in open-flow volumes of individual wells. Average pay thickness is estimated to be approximately 45 feet, but logs of many of the earlier wells fail to designate how much "pay" was encountered and this figure may prove to be incorrect when more data are secured.

Gas is uniformly sweet throughout the Hugoton field and the British thermal unit content averages 1,000–1,025 per cubic foot. Gasoline content is reported to be about 0.4 gallon per 1,000 cubic feet. Gasoline is extracted by the absorption process from all gas taken by the Northern Natural Gas Company which has a gasoline plant near Hugoton, and the Panhandle Eastern Pipe Line Company which has a plant near Arkalon. The Peerless Carbon Black Company operates a carbon plant at Hickock, burning about 3 million cubic feet daily, and the United Carbon Company is completing a plant of similar size near Ryus. Both plants are designed to manufacture a very high grade of carbon black which has special uses and are not to be confused with the ordinary carbon-black plant.

Present development indicates that the Hugoton field extends from somewhere near the Arkansas River at the north, across Texas County, Oklahoma, toward the south and very probably connects with the Amarillo field of Texas. At present the Kansas portion has an apparent proved area of about 1,380,000 acres. By assuming an original shut-in pressure of 440 pounds, an average pay thickness of 45 feet, an average porosity of 20 per cent, and an abandonment pressure

MAJOR GAS FIELDS
AND
NATURAL GAS TRUNK PIPELINES
OF KANSAS

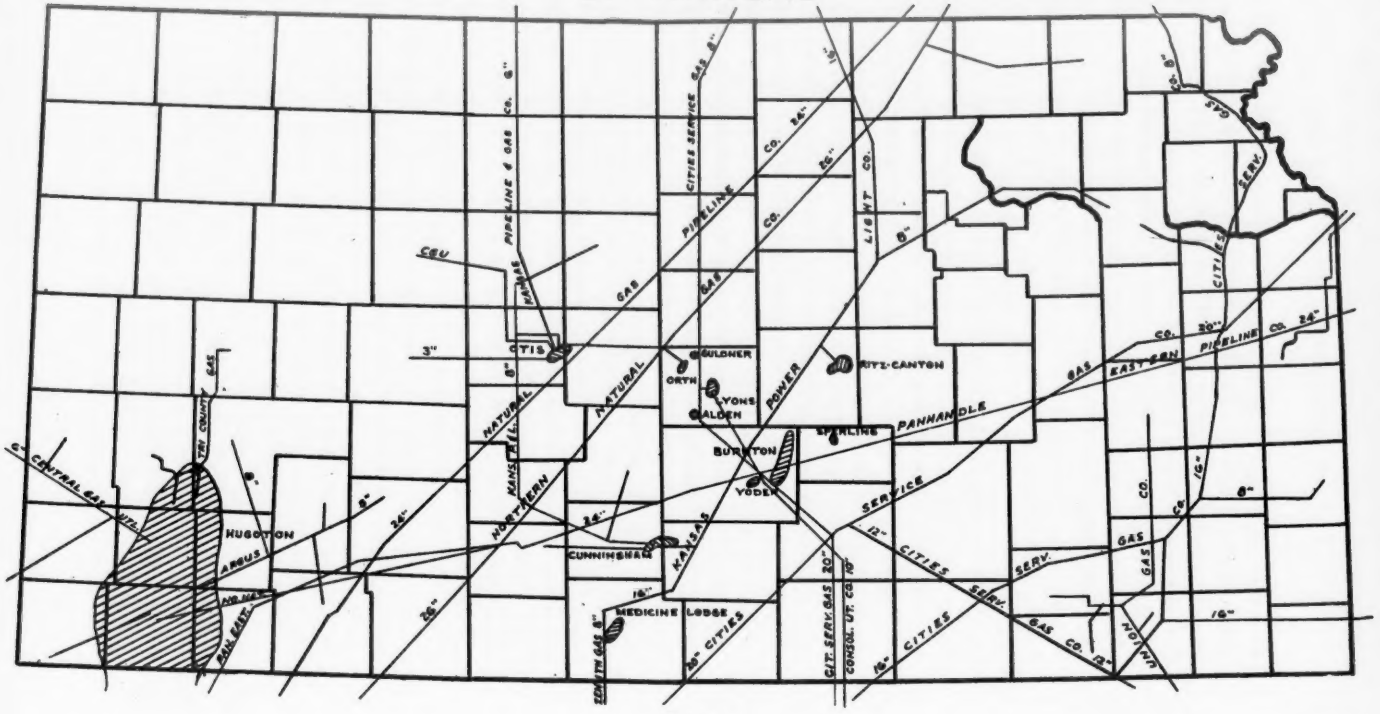


FIG. 2

of 40 pounds, an estimated original recoverable reserve of 9,953,895 cubic feet of gas per acre is found. This figure indicates the original field reserve for Kansas to be 13,736,375 million cubic feet. Withdrawals to January 1, 1940, have been 175,135 million cubic feet. These figures indicate that the field has produced approximately 1.27 per cent of its original recoverable gas.

Nearly all wells are drilled with rotary tools to the top of the first producing zone where casing is set and cemented; a portable spudder is then moved in to drill through the producing formations and complete the well. From 500 to 600 feet of $12\frac{1}{2}$-inch or $10\frac{3}{4}$-inch casing are run and cemented to the top in order to protect the fresh-water zones and either 8- or 7-inch casing is used for the producing string, 2,300 to 2,700 feet usually being run according to location within the field. No tubing is used as the wells make very little if any water and do not require frequent "blowing." Probably the only water produced is either a small amount of connate water or condensate which forms from water vapor contained within the gas. Hydrates have given some trouble in well connections and meter runs at times, especially in the winter months. During the past season individual dehydrators have been tried with good success on certain well lines, with calcium chloride as the absorbing agent. Hydrate solvents have been lubricated into other well lines and freeze-ups thereby prevented. The principal operating problem has been the caving of the softer shale beds which lie between the harder producing beds. Some wells give considerable trouble due to these cavings and cases of complete bridging and plugging of the well bore have occurred. As the pay zones may be distributed through a vertical distance of approximately 400 feet, all open hole, it is easily understood how this can happen. When wells have accumulated enough cavings to seal off a substantial portion of the "pay" it is customary to move in a portable clean-out machine, mounted on a truck, and by the use of light tools, a bailer, and water, the mud is removed and the well put back on production. Nearly all the wells drilled recently have been acidized before completion and some have been shot with nitroglycerine in order to fracture the producing beds and make them more susceptible to the action of the acid. Excellent results have been obtained through the use of 5,000 to 10,000 gallons of acid, in increasing the open flow, and it is not exceptional to experience an increase of several hundred per cent after acid. It is also reported that much less trouble is encountered with cavings in acidized wells so that it appears probable that most of the old wells will eventually be treated. Some wells have been completed with a perforated liner set in the producing formation in order to

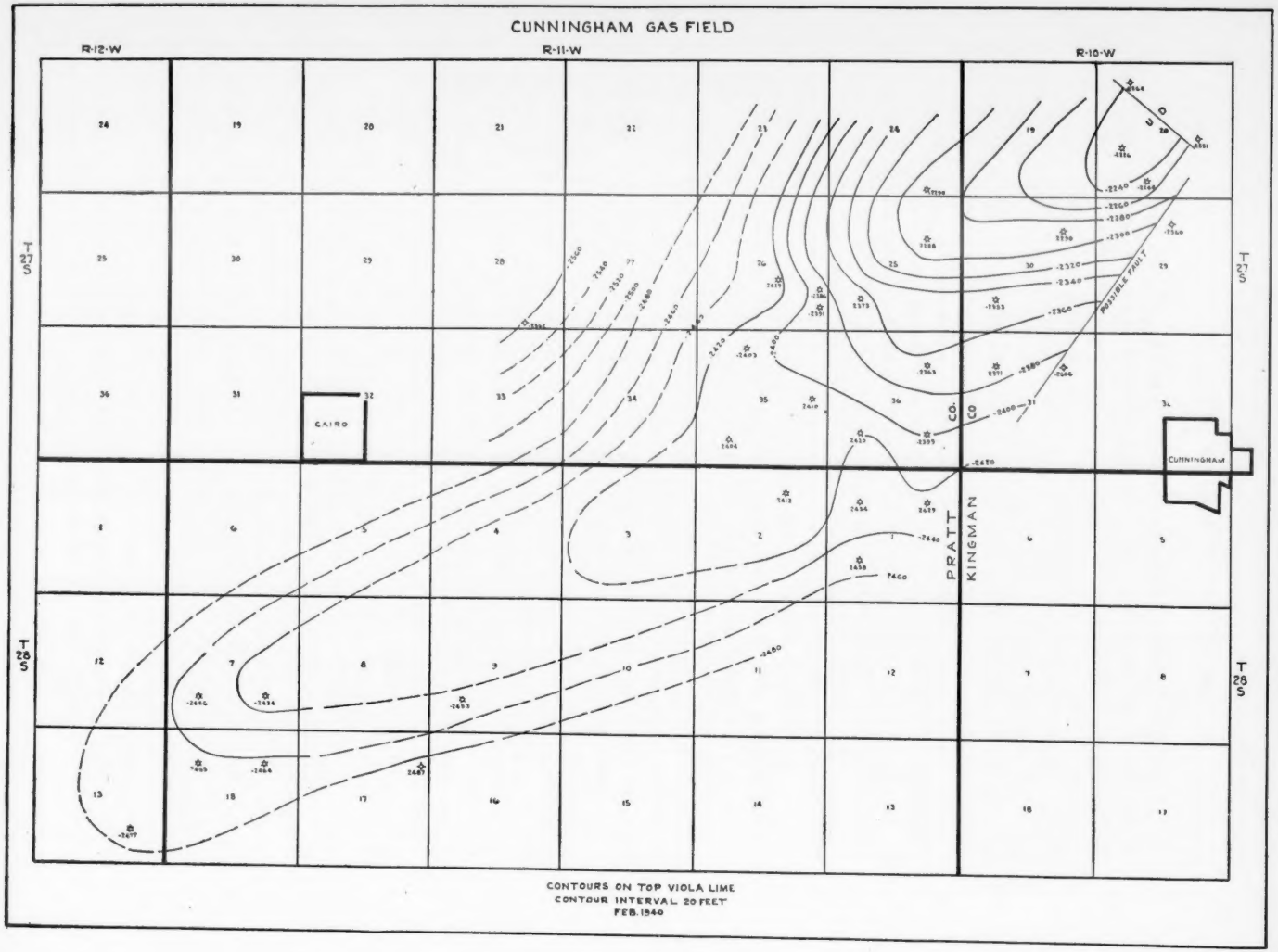

CUNNINGHAM GAS FIELD
R-12-W
R-11-W
R-10-W
T 27 S
T 28 S
GAIRO
CUNNINGHAM
PRATT CO.
KINGMAN CO.
POSSIBLE FAULT
CONTOURS ON TOP VIOLA LIME
CONTOUR INTERVAL 20 FEET
FEB. 1940

FIG. 3

prevent caving, and complete freedom from this trouble has been reported in these wells. Many of the older wells were drilled on 160-acre units but all those drilled in recent years are on 640-acre units and some of the 160-acre wells have had additional acreage unitized with the tracts on which they are located. Owing to the vast size of the field the 640-acre spacing seems to be best as it permits more land owners to share in the development.

Beginning April 1, 1940, the State will allocate production of the field to individual, developed tracts by use of a formula which distributes 80 per cent of the production to the product of acreage times pressure and 20 per cent to open-flow volume. Wells having an acreage of more than 160 have their "acreage-times-pressure" factor increased by 5 per cent for each 10 acres in excess of 160 up to a maximum of 640 acres. A well located on a 640-acre unit will therefore have an "acreage-times-pressure" factor 3.4 times as large as that of a similar well on a 160-acre unit. If the well is located on less than 160 acres this factor is diminished 5 per cent for each 10 acres less than 160.

FIG. 3

CUNNINGHAM GAS FIELD

The Cunningham Viola limestone gas pool owes its discovery to the search for oil in western Kansas. The discovery well was the Skelly Oil Company's Leisman No. 1, in Sec. 20, T. 27 S., R. 10 W., Kingman County. This well was completed in September, 1932, and was drilled in a field already producing oil and gas from the Lansing-Kansas City formations. The Leisman well was drilled to the Viola, Simpson, and Arbuckle formations, encountering large volumes of gas in all three. It was then plugged back to the Viola and completed as a gas well of 56 million cubic feet open flow. Since that time 27 additional Viola gas wells have been completed and the pool appears to be proved for a distance of 9 miles southwest of the discovery well.

The pool did not have a large pipe-line outlet until recently and 21 of the wells have been drilled within the past year. The Kansas Power and Light Company was the only buyer of Cunningham gas until October, 1939, when the Cities Service Gas Company completed a pipe line from Hutchinson to the pool. These two pipe lines provide the only outlets for gas although the Skelly Oil Company, which operates 40 shallower oil wells, is utilizing some Viola gas for pressure maintenance in the Lansing-Kansas City formations.

The wells are all drilled with rotary tools to the top of the Viola and are then drilled in with cable tools. Casing practice is to run 20 feet of 20-inch surface pipe, about 350 feet of 13-inch casing, cementing it to protect fresh-water zones, and then 5- or 7-inch is run on top of the Viola and cemented. The average depth is between 3,900 and

4,100 feet. Initial open-flow volumes range from 1 million to 125 million cubic feet and original shut-in pressure was more than 1,300 pounds per square inch. Acid has been used to increase production in numerous wells with excellent results, the usual amount employed being 1,000 gallons. Spacing practice is almost universally one well to 160 acres.

There are no workable outcrops in the Cunningham pool and it owes its discovery to the core drill. The structure consists of an anticline extending from northeast to southwest and plunging southwest. At the northeast end it is much higher and forms a dome with 160 feet of closure. Dry holes drilled offsetting producing wells in this part indicate that it may be terminated in this direction by faulting, as these dry holes are 300 feet lower than the producing offsets, thus indicating something more than dip. Porosity and pay thickness appear to vary greatly in different parts of the field. In general the larger wells are located in the highest part of the pool. Figure 3 shows the attitude of the top of the Viola limestone and locations of wells drilled deep enough to test this formation.

Not enough gas has been produced, nor has the field been developed sufficiently to make an accurate estimate of present recoverable reserves. To January 1, 1940, only 8,525 million cubic feet had been produced and most of this came from a few wells. On the basis of partly assumed data of an average pay thickness of 20 feet, an average porosity of 15 per cent, a rock pressure of 1,300 pounds, and an abandonment pressure of 300 pounds, the recoverable reserve figure is 8,003,353 cubic feet per acre. The pool appears to cover approximately 10,000 acres, indicating a field reserve of 80 billion cubic feet. This figure is for the Viola gas only and there appears to be a considerable reserve in the Simpson and Arbuckle formations also, although not enough data are available to make an estimate of it. The gas is uniformly sweet and has an average B.T.U. content of 1092 and gasoline content of about 0.2 gallon per 1,000 cubic feet. These figures are for the Viola gas only as data are not available for the deeper gas.

Production is allocated to individual, developed tracts by the State on the basis of acreage times pressure times the square root of the open-flow volume of each developed lease. The top limit on acreage attributable to a well is 320 acres.

OTIS FIELD

The Otis field of Rush and Barton counties was discovered in March, 1930, by Morgan, Flynn, and the Milmac Oil Company, the

discovery well being the Eitel No. 1 in Sec. 11, T. 18 S., R. 16 W. The basis for locating the discovery well was a surface structure mapped on Cretaceous outcrops. There are now 45 gas, 14 combination oil and gas, and 3 oil wells in the pool. There are 5 pipe-line outlets as follows: the Central Gas Utilities Company, the Kansas Pipeline and Gas Company, the Kansas Power and Light Company, the Northern Natural Gas Company, and the Producers Gas Company. The field is nearly drilled up, there being only a few proved locations remaining undrilled. The spacing plan has been one well to 160 acres until recently when a wider spacing has been employed. In order to permit more landowners to share in the production and to avoid unnecessary drilling, some undeveloped tracts have been unitized with developed leases and the wells thereon have had increased allowables given them. Production of the pool is allocated to the individual, developed tracts by the State, using a formula which allocates three-fourths of the production to the product of acreage times shut-in pressure and one-fourth to open-flow volume.

Structurally the field lies on the southwest flank of a buried granite ridge which has an axis extending northwest and southeast. The producing formation has been correlated with the Reagan sand of Oklahoma which is Cambrian in age. It appears either to pinch out or to grade into a hard impervious quartzite on top of the granite ridge where several dry holes have been drilled. On the southwest, at the foot of the slope, there is an accumulation of oil in the lower part of the sand and here are located the combination wells. Depths of producing wells range from 3,500 to 3,600 feet. There appears to be no edge or bottom water and no water drive is present. The field has been limited on the north and south by numerous dry holes but the east and west ends have not yet been determined.

Most of the earlier wells were drilled with cable tools but those drilled recently have nearly all been drilled with rotaries. Where drilled with rotary tools it is customary to set about 200 feet of $15\frac{1}{2}$-inch pipe, 900 feet of 10-inch, and either 5- or 7-inch on top of the sand. All strings are cemented and left in the hole. Some rotary wells have been drilled-in with cable tools and others were rotaried from top to bottom. None of the wells has been shot, all producing naturally, both dry gas and combination wells.

Most of the wells produce gas with some hydrogen sulphide content so that it is necessary to treat it before transporting it to market. Two sulphur-treating plants are in operation and serve the entire field. These plants belong to the Northern Natural Gas Company and the Producers Gas Company and are functioning very satisfactorily.

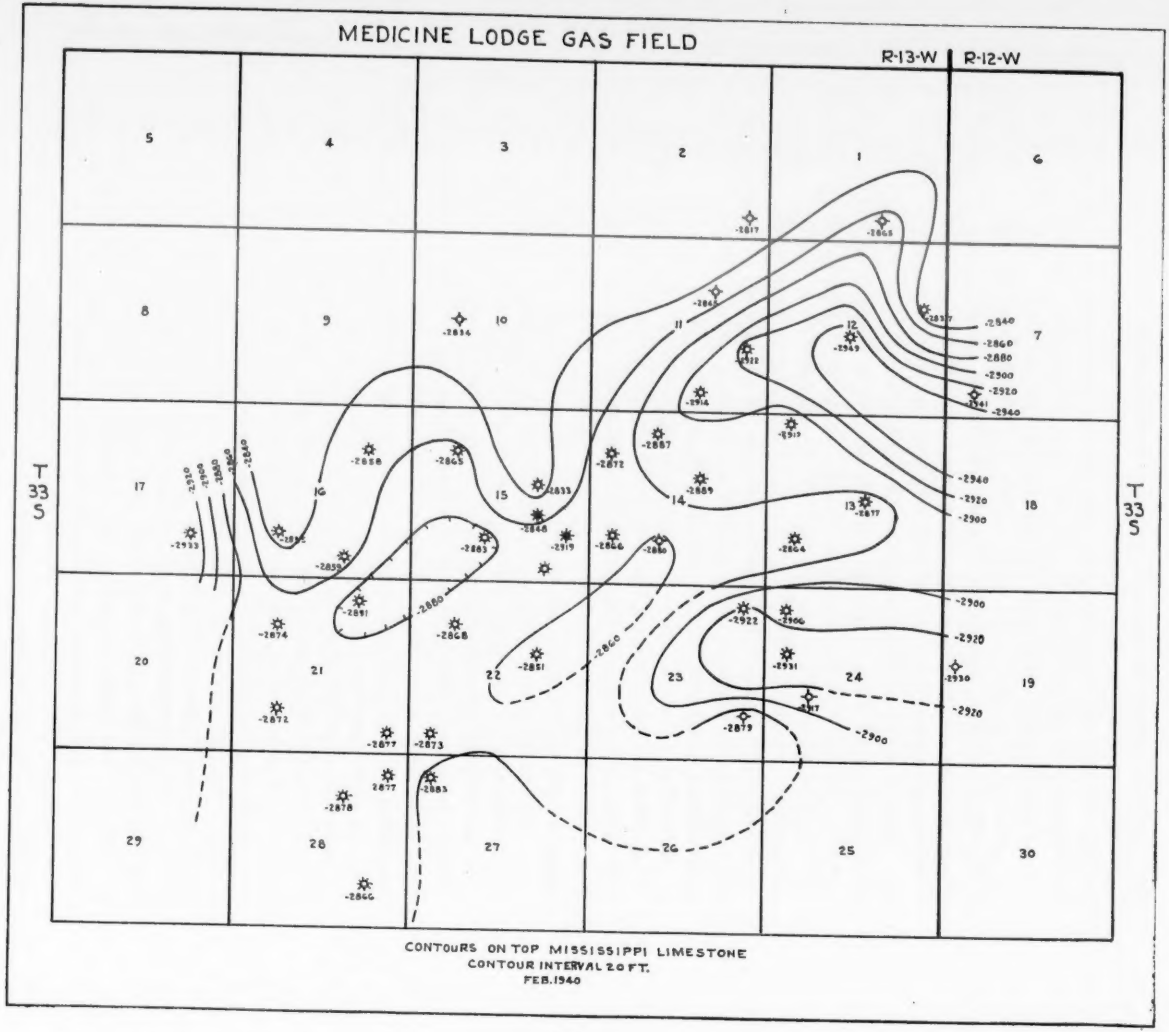

MEDICINE LODGE GAS FIELD
R-13-W
R-12-W
T 33 S
T 33 S
CONTOURS ON TOP MISSISSIPPI LIMESTONE
CONTOUR INTERVAL 20 FT.
FEB. 1940

FIG. 4

Reserves have been computed by use of the following partly assumed data: average pay sand thickness of 30 feet, porosity 15 per cent, present average shut-in pressure of 722 pounds gauge, abandonment pressure of 100 pounds. Using these data gives an estimated recoverable reserve of 7,600,000 cubic feet per acre. With an estimated pool area of 15,000 acres an indicated reserve of 114 billion cubic feet is reached.

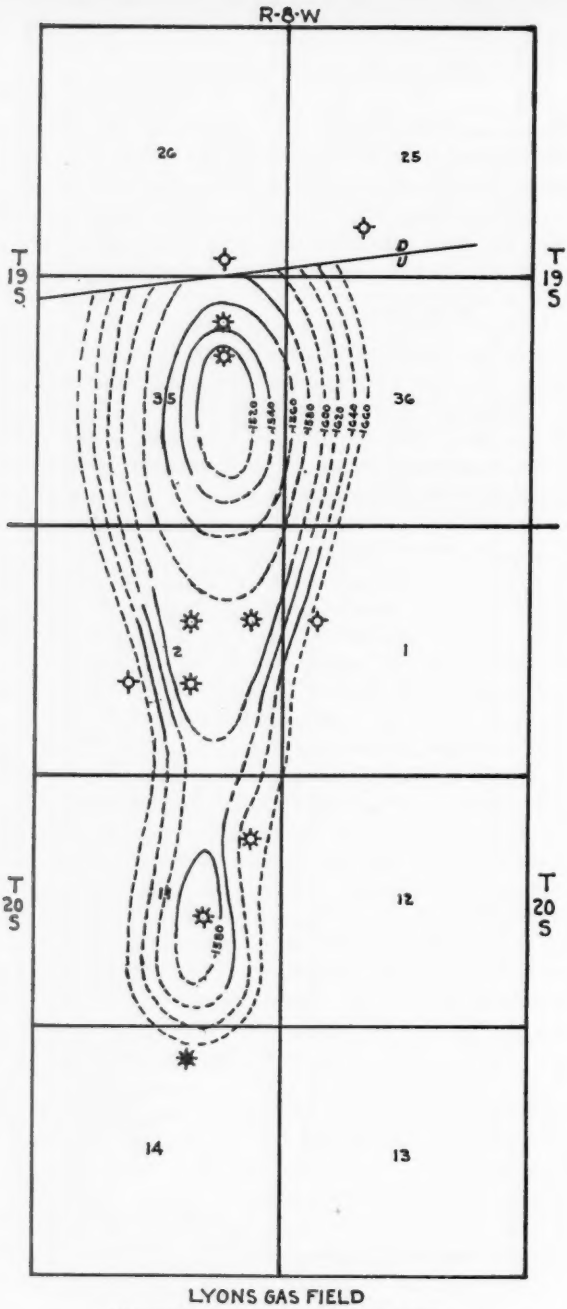
MEDICINE LODGE

The Medicine Lodge gas pool of Barber County was discovered in January, 1927, by the Barbara Oil Company, the discovery well being the Alexander No. 1, located in Sec. 13, T. 33 S., R. 13 W. The basis for location of the discovery well was surface structure together with some subsurface information. Gas production is encountered in the Mississippian limestone and is found in the top, or "chat" portion, of this formation and also in sandy limestone zones below the "chat" but in the upper part of the limestone.

Two wells are producing oil from the Viola limestone and one well produced oil for a time from Simpson sand. The entire developed field belongs to one company and drilling has been carried on in a very orderly manner, the spacing plan averaging one well to 160 acres. There are 32 gas wells at present, all producing from the Mississippian limestone and the operating company keeps one string of tools drilling additional wells most of the time. The field has a very good pipe-line market for gas, this being afforded by the Kansas Power and Light Company and the Zenith Gas Company. The wells are drilled with rotary tools to the top of the Mississippian limestone where casing is set and cemented and they are then drilled-in with cable tools. From 200 to 300 feet of 10-inch or 12½-inch surface pipe is set and cemented and the production string consists of 4,400–4,600 feet of 7-inch casing. Some wells have been shot and some treated with acid. The field had a reported initial shut-in pressure of 1,625 pounds gauge and present average well pressure is 1,261 pounds. However, individual well pressures still are as high as 1,584 pounds. The largest reported initial open-flow volume was 50 million cubic feet, and the smallest 1 million cubic feet, the average size being about 11,500,000 cubic feet. The field has been a very good gas producer, having marketed a total of 36,437,112,000 cubic feet to the end of 1939, which figure does not include gas used for development operations.

Figure 4 shows the attitude of the top of the Mississippian limestone by means of contours having a 20-foot interval. It will be noted that structure appears to have very little to do with the gas accumulation. The entire field, in general, lies on a slope dipping southeast

FIG. 4



LYONS GAS FIELD
CONTOURED ON TOP ARBUCKLE LIME
CONTOUR INTERVAL 20 FT.
FEB. 1940

FIG. 5

and production is encountered at points having a difference in elevation of more than 100 feet. Two rather deep synclinal areas are found along the east side of the pool but these both produce gas and one dry hole is located in a high area in the southwest quarter of Section 14. It appears probable that the gas, which occurs in porous zones which form the reservoir, is confined there by a wedging-out of these porous zones or a change in lithologic character, the porosity becoming less at the edges of the field.

There appears to be little, if any, water drive present and very little water is produced with the gas. On the assumption of an original pressure of 1,625 pounds, there has been a drop of 364 pounds to December 31, 1939. The field has marketed 36,437,112,000 cubic feet, and this, together with an estimated 1,500 million cubic feet used for development, gives a total production of approximately 38 billion cubic feet. Dividing this by 364 pounds gives a yield of 104 million cubic feet per pound pressure drop. By assuming an abandonment pressure of 300 pounds there still remain 961 pounds of available pressure, which, if multiplied by 104 million cubic feet indicates a recoverable reserve of 99,944 million cubic feet. Since the field is not fully defined as yet, this figure may require considerable revision as more data are secured.

LYONS

The first gas well completed in the Lyons pool was the Atlantic Refining Company's Pulliam 1-A, located in the N. ½ of NE. ¼ of Sec. 35, T. 19 S., R. 8 W., Rice County. This well was completed in August, 1936, in the Arbuckle limestone, with an open-flow volume of 150 million cubic feet and a shut-in pressure reported at 1,060 pounds. A well drilled by the Shell Oil Company approximately 2 miles south of the Pulliam well had already proved the existence of gas on the Lyons structure but had encountered mechanical difficulties and was not completed until 1939. Both tests were the result of seismograph exploration which found a buried structure that could not be mapped by surface geology due to lack of workable outcrops.

At present, there are five wells producing from the Arbuckle, two from the Simpson sand, and one from both Arbuckle and Simpson. This last well has separated the two formations by means of a tubing packer, Arbuckle gas being produced through 3-inch tubing and Simpson gas through the casing head. All gas produced from the Arbuckle limestone contains considerable hydrogen sulphide and that from the Simpson sand contains a small amount. The Cities Service Gas Company, which provides the only market outlet for the pool, has constructed a sulphur-treating plant located within the pool which

extracts the hydrogen sulphide and renders the gas suitable for all purposes. All the wells produce a considerable amount of very volatile condensate which is caught in high-pressure separators at each well.

The pool is not yet drilled up and the spacing plan, with one exception, has been one well to each 80 acres. One well is located on a 120-acre lease unit. The wells are all drilled with rotary tools to the top of the Arbuckle where casing is cemented and drilling-in is done with cable tools. Casing practice is to set and cement about 150 feet of 8-, 10-, or 12-inch casing and about 3,300 feet of 5-, 7-, or 8-inch. Three of the Arbuckle wells have been acidized with very good results. There is undoubtedly a water drive present in the Arbuckle limestone and probably also in the Simpson sand. As the abandnment pressure is unknown, it is difficult to make an estimate of the recoverable gas reserves.

Figure 5 is contoured on the top of the Arbuckle with a 20-foot contour interval. It appears that the structure is fairly well defined at present, there having been four dry holes completed which limit it on the north, east, and west. Accumulation is undoubtedly due to a water drive forcing the gas to the higher part of the anticline. No oil appears to be present in the Arbuckle as the dry holes failed to encounter any, but the southernmost well, which produces from the Simpson, is a combination oil and gas well having an oil potential of 140 barrels per day. It is operated, however, as a gas well and produces oil only incidental to its gas allowable.

Gas runs from the pool are regulated by a Kansas Corporation Commission "ratable take" order, the proration formula allotting five-eighths of the production to the product of acreage times well pressure and three-eighths to open-flow volume.

BURRTON FIELD

The Burrton field was discovered in April, 1931, the discovery well being the Blake No. 1, drilled by the Shell Oil Company and the Continental Oil Company and located in Sec. 23, T. 23 S., R. 4 W. Gas production was encountered in the upper, or "chat" part of the Mississippian limestone. The discovery well was later deepened, oil encountered, and it became a "combination" well. Most of the chat wells in the Burrton field have produced both oil and gas, and, as the field was almost entirely drilled up with casing set on top of the gas "pay," a great deal more gas was produced than could be marketed. This gave rise to a large amount of wastage although most of the gas was run through one of the three gasoline plants located within the field. Some wells were completed with two strings of casing, permitting the gas to

be separated from the oil and many such wells have produced and marketed a large amount of dry gas. In certain parts of the field the gas is sour and some of it is unfit for domestic use. No sulphur-treating plant was constructed to extract the hydrogen sulphide as there was insufficient gas market to justify the expenditure.

The field covers about 13,000 acres and the average producing depth is 3,300–3,400 feet. The original spacing plan was one well to 40 acres but after oil was discovered this was changed to 10-acre spacing. Original open-flow volumes ranged as high as 98 million cubic feet and shut-in pressure was reported to be 1,200 pounds. The field is located on a large buried anticline which was discovered by the core drill. Oil production in the deeper Hunton limestone has been developed also in a small part of the field but little gas was encountered in this formation. A few wells have been drilled within the past year but the pool is almost entirely defined and drilled up. Most of the present well pressures are less than 100 pounds and very few wells are capable of feeding gas into the dry-gas pipe lines. Nearly all wells make a considerable amount of salt water and are on the pump. The field is mentioned here, not because it has a large present gas reserve, but because it is the most outstanding example in Kansas of gas wastage which has occurred in the past. If the wells had all been properly completed by setting casing between the gas and oil "pays," a large part of the gas would undoubtedly have been preserved, to be marketed at a later date. Conditions such as have existed at Burrton are not found in any of the newer oil and gas pools in Kansas and the State has found the oil industry willing to assist in every way possible in carrying out gas conservation.

McPHERSON COUNTY

McPherson County has many gas pools within its borders, the first production having been found in September, 1926. Most of the gas pools have been drilled up for some time, and, while still containing large reserves, they are all on a decline at present. Nearly all the gas production has been found in the Mississippian limestone and most of it has been associated with oil. Various pools will produce gas commercially for some years to come but water encroachment will eventually terminate this production as edge or bottom water is present in all of them. The county is still important as a gas producer but unless new pools are discovered it is doubtful if it has more than 75–100 billion cubic feet of recoverable gas reserves remaining.

There are various small gas pools in western Kansas, the potentialities of which are not fully known. Within the past year, gas was discovered in two wells drilled in Sherman County. Logs of these wells

MAJOR KANSAS GAS POOLS

Pool	County	Discovery Date	Number of Wells	Average Depth (Feet)	Producing Formation	Estimated Proved Acreage	Average Well Open Flow, MCF.
Cunningham (Viola)	Kingman Pratt	Sept., 1932	28	3,950–4,300	Viola lime	10,000	40,800
Hugoton	Finney Haskell Kearney Seward Grant Stevens Morton	Dec., 1922	284	2,600–2,700	Permian Limestones Dolomites	1,380,000	8,600
Lyons	Rice	Aug., 1936	8[1]	3,300	Arbuckle ls. Simpson sd.	1,120	20,000
Medicine Lodge	Barber	Jan., 1927	32	4,500–5,000	Miss. lime	8,000	8,900
Otis	Rush Barton	Mar., 1930	59	3,505	Reagan sd.	15,000	27,600

Pool	Average Well Pres. Lbs./Sq. In.	Total Pool Open Flow MCF.	1939 Production MCF.	Total Production to 12-31-39, MCF.	Developed Acreage	Estimated Reserve MCF.
Cunningham (Viola)	1,291	1,143,578	2,453,079	8,525,362	4,850	80,000,000
Hugoton	412	2,445,156	28,964,493	188,964,000	117,713	13,500,000,000
Lyons	994	180,600	2,838,722	5,051,284	760	[2]
Medicine Lodge	1,261	287,500	6,380,558	38,000,000	6,200	100,000,000
Otis	724	1,628,600	8,062,919	44,426,000[3]	9,830	114,000,000

[1] One well producing from both Simpson and Arbuckle.
[2] Insufficient data to estimate reserves.
[3] Includes gas marketed only.
MCF: 1,000 cubic feet.

are not available but they are reported to be producing from a depth of about 1,100 feet from a sand encountered in beds of Cretaceous age. The importance of this discovery is not yet known but it has proved that these younger beds have some possibilities. Of the 105 counties which make up the state, commercial gas production has been found in 53 and undoubtedly as the search for oil goes on, other counties will join the ranks of the producers. The state occupies seventh position nationally in gas production at the present time but both proved reserves and markets are increasing and as the older fields of some of the other states decline this position will probably improve.

KANSAS GAS "SANDS"

Cretaceous sand		Oswego shale
Herington limestone		Squirrel (Prue) sand
Krider dolomite		Upper Bartlesville sand
Winfield limestone		Lower Bartlesville sand
Fort Riley limestone		Burgess sand
Florence flint		Mississippi chat
Admire shale		First break
Stalnaker sand Layton sand limestone	Lansing-Kansas City	Sandy zones in Mississippian limestone
Red sand		Misener sand
Peru sand		Viola limestone
Weiser sand		Simpson sand
Oswego limestone sand		Arbuckle dolomite
		Reagan sand

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 10 (OCTOBER, 1940), PP. 1798-1804, 1 FIG.

RELATIVE POROSITY AND PERMEABILITY OF PRODUCING FORMATIONS OF HUGOTON FIELD AS INDICATED BY GAS WITHDRAWALS AND PRESSURE DECLINE[1]

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ABSTRACT

In the Hugoton gas field in southwestern Kansas wells have been producing gas for approximately 12 years, and have declined more than 10 per cent from their initial pressure. With data from 284 wells available it is now possible to study the relation of pressure decline and well spacing to the total gas withdrawals weighted with respect to acreage in areas of equal pressure decline. The recent practice of treating the dolomitic limestone producing formations with acid has introduced a new complex factor into this study.

INTRODUCTION

The Hugoton gas field in the southwestern corner of Kansas had on July 1, 1939, 284 wells, of which 254 were producing at that time and are considered in this paper. It includes an area 60 miles long and 20–40 miles wide, in parts of seven counties. The large gas-producing area in Texas County, Oklahoma, and in Sherman and Hansford counties, Texas, is geologically a part of the same field but these wells have not produced sufficient gas to be considered in this study.

The general geology of the Hugoton field is well known through the publications of Cotner and Crum,[4] Rogatz,[5] Hemsell,[6] and others. Aside from local Quaternary sand dunes the surface formations which almost completely cover the region are Tertiary Ogallala sand and gravel. Beneath these Cenozoic clastic deposits may be found patches of Mesozoic, Cretaceous Dakota sandstone, and Triassic redbeds. There is everywhere a thick section of Permian Cimarron red shales, anhydrites, and salt deposits. The gas-producing formations are in the Big Blue series of the Permian immediately underlying the Cimarron. They consist of dolomitic limestones with which are interbedded highly colored shales. The youngest dolomite which bears gas is the

[1] Read before the Association at Chicago, April 12, 1940. Manuscript received, April 20, 1940.

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[4] Victor Cotner and H. E. Crum, "Geology and Occurrence of Natural Gas in the Amarillo District," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 8 (August, 1933).

[5] Henry Rogatz, "Geology of Texas Panhandle Oil and Gas Fields," *ibid.*, Vol. 19, No. 8 (August, 1935).

[6] Clenon C. Hemsell, "Geology of Hugoton Gas Field of Southwestern Kansas," *ibid.*, Vol. 23, No. 7 (July, 1939).

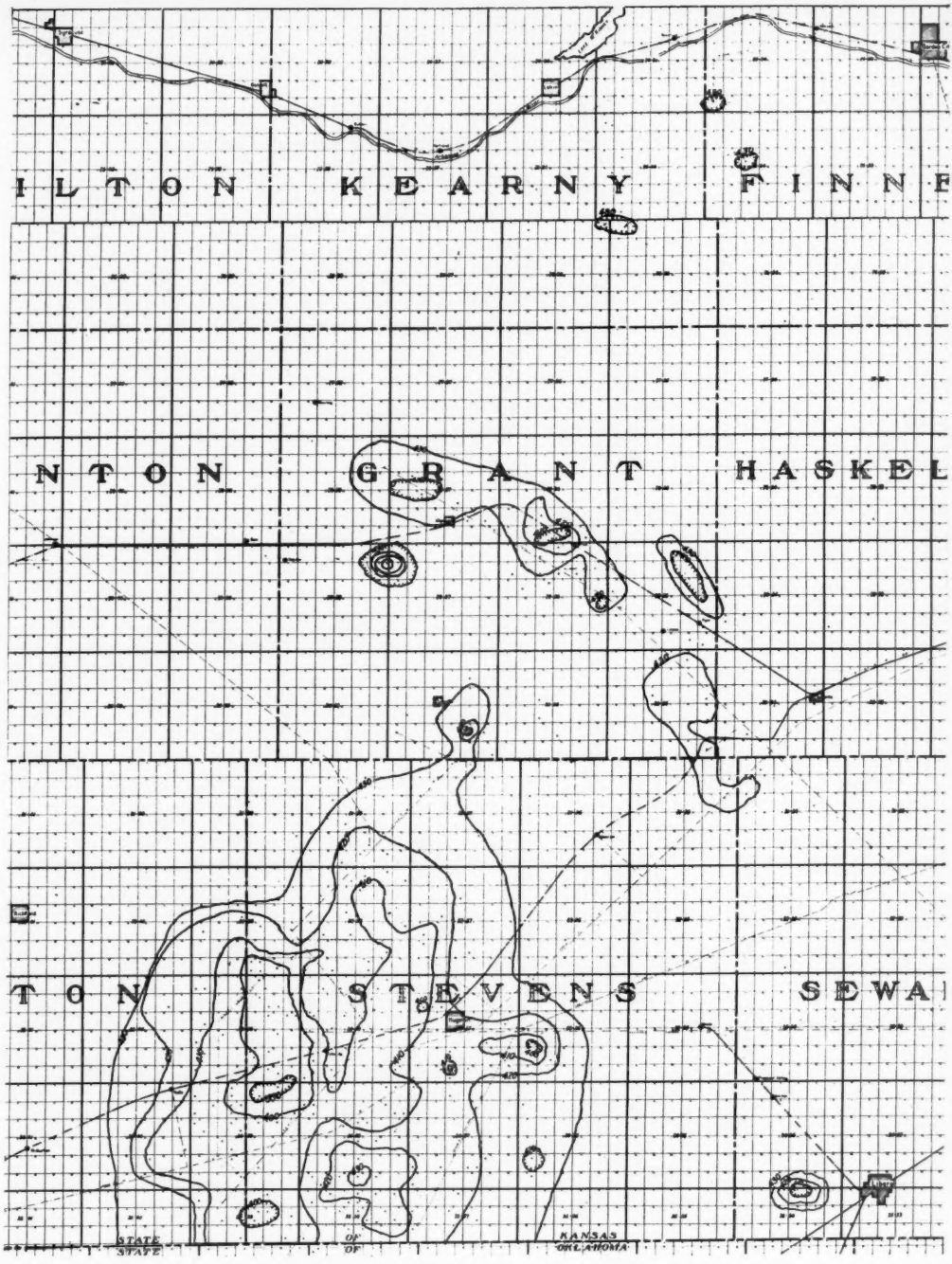

FIG. 1.—Map showing lines of equal rock pressure in Hugoton field, Kansas.

TABLE I

HUGOTON FIELD OF KANSAS—WITHDRAWAL, PRESSURE, AND ACREAGE DATA

No. of Wells	Gas Withdrawal to 7/1/39 MCF	Pressure		Pressure Decline Lbs. per Sq. In.	Withdrawal per Lb. Decline to 7/1/39 MCF	Acres in Area Considered	Withdrawal per Acre to 7/1/39 MCF	Calculated Initial Reserve per Acre to 7/1/39 MCF	Total Initial Reserve of Area MCF	Present Press. Multiplied by Acreage
		Initial Lbs. per Sq. In.	Present Lbs. per Sq. In.							
6	5,108,145	435	387	48	106,420	1,280	3,991	36,166	46,292,700	495,360
1	286,234	435	393	42	6,815	640	447	4,632	2,964,525	251,520
26	27,794,536	435	395	40	694,863	16,640	1,670	18,165	302,265,405	6,572,800
8	9,771,888	435	397	38	257,155	2,240	4,362	49,939	111,862,425	889,280
34	24,424,346	435	404	31	787,882	48,000	509	7,140	342,728,670	19,392,000
22	21,242,460	435	405	30	708,082	30,080	706	10,240	308,015,670	12,182,400
4	1,779,402	435	410	25	71,176	2,880	618	10,751	30,961,560	1,180,800
77	51,973,830	435	415	20	2,598,692	110,720	469	10,210	1,130,431,020	45,948,800
5	839,261	435	418	17	49,368	2,880	291	7,457	21,475,080	1,203,840
1	98,084	435	419	16	6,130	640	153	4,166	2,666,550	268,160
43	12,344,669	435	425	10	1,234,467	146,560	84	3,664	536,993,145	62,288,000
8	1,393,368	435	432	3	464,456	5,120	272	39,461	202,038,360	2,211,840
19	3,947,045	435	433	2	1,973,523	11,520	343	74,521	858,482,505	4,988,160
254	161,003,268	435			8,959,029	379,200	425	10,277	3,897,177,615	157,872,960

Average acres per well: 1,493 acres.
Average pressure weighted with respect to group acreage: 416.33 pounds per square inch.
Percentage withdrawal of original reserve under 379,200 acres of field: 4.13 per cent.
MCF = 1,000 cubic feet.

Herington, the next is the Krider, next lower is the Winfield, the chief gas producer, and small quantities of gas may be encountered as low as the Fort Riley and Florence limestones.

METHOD OF STUDY

As may be seen in Figure 1, the western part of Stevens County is fairly well developed. Some of these wells are 12 years old and have been producing substantial amounts of gas since they were first connected into the pipe-line systems in 1930. The original rock pressure, 435 pounds per square inch, has been reduced in one small area to 384 pounds and in other spots to 395 pounds. The map shows lines of equal rock pressure based on the present shut-in well-head pressures and indicates the pressure to be expected in the areas adjacent to the wells.

The average initial open flow of untreated wells in this field during the first 10 years of the development was about 7 million cubic feet per day. Since the time that wells have been treated with acid the open flow of the entire field has been greatly increased. For this reason it is not practicable to study this field on the basis of decline of open flow and in this article attention is given entirely to the method of decline of rock pressure. There is no evidence to date of any encroachment of water in the producing formations; therefore, the method of rock-pressure decline should be unusually reliable.

Table I shows the pressure decline of various areas and the production which has been realized for this decline. The figures are weighted with respect to acreage on the basis of areas of equal decline. The production figures are complete for the metered gas which has been delivered to any and all pipe lines. Unmetered gas is not a large factor in this field since there have been no conspicuous "blow-outs" of uncontrolled wells. It may be estimated that the gas lost while drilling-in the 254 wells totaled $6\frac{1}{2}$ billion cubic feet and that the loss of gas by the annual measurement and by blowing wells for conditioning is about $\frac{1}{2}$ billion cubic feet to date. This total of about 7 billion cubic feet of unmetered gas is less than 5 per cent of the metered gas.

It is recognized that the bottom-hole pressures are somewhat greater than the well-head pressures used in the table. Since the limits of production vary in depth only from about 2,400 feet to about 2,900 feet, the weights of the columns of gas in individual wells are almost equal and will not seriously affect the calculations used in estimating the decline of gas reserves.

No effort was made to correct for the absolute temperature and absolute pressure found at the sand face since these corrections prac-

tically nullify one another. Analyses show an average content as follows.

	Percentage
Methane	81.0
Nitrogen	8.6
Ethane	4.9
Propane	3.3
Butane	1.3
Pentanes plus	.6

There is no hydrogen sulphide, carbon dioxide, or oxygen in this gas. The heat value varies from 948 to 1,041 British thermal units per cubic foot. The deviation from Boyle's law for gas of this composition is less than 4 per cent at the maximum pressure and was not considered. The specific gravity of the gas in this field is between 0.690 and 0.700.

POROSITY

A study of logs of 183 of the wells with the most complete production records shows an average thickness of the producing formations of 40.4 feet. The productive formations occur at intervals throughout approximately 250 feet of section.

Table I indicates an average initial reserve of 10,277,000 cubic feet per acre in the developed part of the field. The calculated bottom-hole pressure, on the assumption of an initial well-head shut-in pressure of 435 pounds, is 462 pounds, or 31.43 atmospheres. The initial reserve of 10,277,000 cubic feet would occupy a space of only 326,981 cubic feet per acre at this pressure. This is equivalent to a space whose dimensions are one acre in area by 7.5 feet in thickness. Since production is derived from formations 40.4 feet in thickness, and the gas within these formations occupies a space 7.5 feet thick, this indicates a porosity of approximately 18.6 per cent.

PERMEABILITY

In the area of lowest pressure, as indicated in Figure 1, the withdrawal per acre to date is about 4 million cubic feet, which indicates that the gas withdrawn is as if from an initial reserve of about 36 million cubic feet per acre. In another low-pressure area the withdrawal per acre to date is 1.7 million cubic feet, which indicates that the gas withdrawn is as if from an initial reserve of about 18 million cubic feet per acre. In intermediate areas the withdrawal per acre to date is ½ million cubic feet, which indicates that the gas withdrawn is as if from an initial reserve of about 10 million cubic feet per acre. On the other hand, in the area of small pressure decline, still comparatively undeveloped, the withdrawal to date is only 84 thousand cubic feet per acre, which indicates that the gas withdrawn is as if from an

initial reserve of only 3.6 million cubic feet per acre. If the field is taken as an average it is found the withdrawal per acre to date is 425,000 cubic feet, which is as if from an initial reserve of 10,277,000 cubic feet per acre. The present average pressure weighted with respect to acreage was found to be 416.3 pounds.

It will be noticed that the writers have not assigned an arbitrary acreage figure per well but have used the total area between wells of similar pressure decline. In the most closely drilled area the wells of lowest pressure are $\frac{1}{2}$–$1\frac{1}{4}$ miles apart. In the region of medium decline the wells are $\frac{1}{2}$–$2\frac{1}{4}$ miles apart. In the region of least decline the wells are 1–$3\frac{1}{2}$ miles apart. At the present stage of development there is one well for each 1,493 acres.

Wells drilled recently do not have the full advantage of the original field pressure. For example, while a new well drilled 1 mile from producing wells showed slightly more pressure than those being produced, it did not have original field pressure; in fact, it had less than the present pressure of a 9-year-old unconnected well $2\frac{1}{2}$ miles from production.

It is probable that the permeability of the field varies considerably throughout the field. There is some evidence, also, that the sphere of influence of a well may extend much farther in one direction than in others. This is not surprising since the productive formation is limestone which is characteristically rilled and jointed so that the porosity is heterogeneous.

In the light of this study, it is evident that (1) the wells in the area of greatest decline are pulling from an extremely large reserve, or (2) there has been at least a partial equalization of pressure between wells more than 3 miles apart, or (3) there is a combination of the first two conclusions.

Attention is called to the fact that these figures are based on only the developed parts of the Hugoton field and include only 379,200 acres. Other students have estimated the total extent of the field to be $1\frac{1}{2}$ million acres in Kansas alone. While approximately 4 per cent of the gas in the developed field has been withdrawn a much smaller percentage of the total field has been taken.

EFFECT OF ACID

The use of hydrochloric acid in treating the dolomitic limestone producing formations in an attempt to increase the open-flow capacities began in 1936 in the Hugoton field and has been in common use since 1938. While treatments have varied from 500 gallons to 18,000 gallons, the recent tendency is to use about 8,000 gallons per well applied in two or three stages.

A few wells apparently have not responded to treatment but most wells have increased in open-flow capacity about 200 per cent. The maximum percentage increase is about 900 per cent and the maximum actual increase in any one well is 33 million cubic feet open flow per day, from 9 million to 42 million cubic feet. No wells have shown a decrease in open flow nor have they been harmed otherwise by acid treatment.

Obviously the total amount of gas in the producing formations is not changed by acid treatment but the immediate productive capacity of the wells is increased. The question arises as to how long this increase will be maintained. While there has not been sufficient time to answer this question definitely the open flow of wells treated $2\frac{1}{2}$ years ago has not declined any more than that of untreated wells.

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SAXET OIL AND GAS FIELD, NUECES COUNTY, TEXAS[1]

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ABSTRACT

The Saxet field was known as a gas field from the date of the completion of the discovery gas well in January, 1923, until August, 1930, when the first oil well was completed. Since that time the history of the field has been a combination of a series of discoveries of new sands, most of which came at a time when the field no longer appeared to hold possibilities of additional production. The field has produced more than 42 million barrels of oil from 30 different sands and in excess of 200 billion cubic feet of gas exclusive of wastage, and on March 1, 1940, had a daily allowed production of 17,320 barrels of oil and distillate and an estimated 155 million cubic feet of gas. 893 wells have been drilled in the 9,100 productive acres, 560 of which still produce oil and distillate.

The highly faulted conditions presented by the field together with its many producing sands make a complicated but interesting problem, the solution of which would have been impossible without the use of electrical logs. A major fault curving through the field from northeast to southwest, and downthrown on the east or coastward, divides the field. Closure pattern is complicated by smaller and compensating faults which form a step-graben on the downthrown side of the major fault. Cross sections made up of electrical logs clearly show that small faults on the upthrown side of the major fault at places intersect in such a manner as to result in a graben in the upper beds which is underlain by a horst in the lower beds. The structure on the upthrown side of the major fault is an anticline trending northeast and southwest and faulted on both flanks while on the downthrown side the structure is a broad nose, arrested by several minor faults and gently plunging southeast. An unconformity is shown by movement of several of the minor faults on the upthrown side of the major fault having ceased with the deposition of the thickest member of the Greta sand series. That movement along the fault planes was coincident with deposition is shown by a thickening of section for the downthrown block as the fault plane is approached, resulting in an increased throw with depth. A study of oil accumulation indicates that the original structure was on the upthrown side of the major fault. Strong evidence for the migration of gas along the plane of the major fault is presented by the many highly charged shallow gas sands on the downthrown side. Most of the field's blow-outs have resulted from these sands.

INTRODUCTION

The scarcity of published data pertaining to the problems of structure and accumulation of oil and gas in the Saxet field probably results from a lack of interest which was caused by the highly divided fee ownership and the class of production obtained prior to the spring of the year 1936.

In October, 1930, W. Armstrong Price[3] wrote a note on the discovery of oil in the Saxet gas field. The note deals in the main with the discovery well alone but reference to various oil and gas showings is made.

[1] Read before the Association at Oklahoma City, on March 24, 1939. Manuscript received, May 9, 1940.

[2] District geologist, Corpus Christi district, Barnsdall Oil Company of Delaware. Present address, consulting geologist, Nixon Building.

[3] W. Armstrong Price, "Discovery of Oil and Gas in the Saxet Gas Field, Nueces County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 10 (October, 1930), p. 1351.

In August, 1933, Price, in his paper, "Rôle of Diastrophism in Topography of Corpus Christi Area, South Texas,"[4] discussed structure indicated by surface topography and arrived at the conclusion that the Saxet structure was an eastward-plunging, elongate nose with an east-west axis. The structure indicated by this topographic feature was substantiated by subsurface work on shallow-water sands and is still in evidence on the contour map of the 4,000-foot sand (Fig. 5) of this report. Further, Price indicated what he refers to as a "fault-line scarp" which rather closely coincides with the projected surface trace of the major fault which effectively separates the field in halves. The "fault-line scarp" of Price's report is indicated by increased slope of the coastal plain just northwest of the town of Clarkwood.

This increase in the slope of the coastal plain and the fact that there is a marked constriction of Nueces Bay between the Saxet and White Point fields was first noted in published work by Alexander Deussen.[5] Deussen interpreted this feature to be a portion of what he called the "White Point anticline." It is interesting to note that Deussen stated: "Faults may accompany the anticline, which is buried beneath Pleistocene formations and has only the faintest surface expression, produced by recent movements along it."

In April, 1934, A. E. Getzendaner[6] postulated the presence of a large fault which he based on paleontological data but which was not readily apparent from the correlation of graphic well logs. At that time there was an undrilled area about 3,000 feet wide separating the old and new portions of the field. It was in this undrilled area that the rapid dip took place which Getzendaner considered to be a fault and which now, of course, has proved to be a fault.

Since the publication of these notes and excerpts from papers, development has been so rapid, conditions of structure so complicated and producing sands so numerous as to discourage the writing of a paper.

Although Saxet is not the first oil field discovered in the South Texas Gulf Coast, nor is it the most important from a reserve standpoint, it has at the present time produced more oil than any field in the district and covers approximately 9,100 acres in which almost 900 wells have been drilled.

[4] *Idem*, "Rôle of Diastrophism in Topography of Corpus Christi Area, South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 8 (August, 1933), pp. 949–51.

[5] Alexander Deussen, "Geology of the Coastal Plain of Texas West of Brazos River," *U. S. Geol. Survey Prof. Paper 126* (1924), pp. 132, 134–35.

[6] A. E. Getzendaner, "McFaddin-O'Connor, Greta, Fox, Refugio, White Point, and Saxet Fields, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 4 (April, 1934), pp. 522–23, 527–28.

The purpose of this paper is to depict the conditions of structure, sedimentation and accumulation of oil and gas in the Saxet field as clearly as possible without spending too much time on conjecture as to why and how these things happened. The paper is based on a careful study of 458 electric logs, 24 cross sections, 14 contour maps, 5 isopach maps and a detailed study of gas-oil and oil-water contacts.

ACKNOWLEDGMENTS

Acknowledgment is made to the Barnsdall Oil Company of Delaware for permission to publish this work; to associate geologists N. P. Brown and Mark L. Orr, who assisted in the making of the many cross sections; to the many operators in the field for their electrical logs used in the cross sections; to Herschel H. Cooper, P. A. Myers, A. E. Getzendaner, J. D. Hedley, Carl Richardson, A. M. Cole, and John Clayton for their many helpful comments and criticisms; to W. G. Blake, editor of the oil news section of the Corpus Christi *Caller-Times*, and to many other individuals and geologists who have contributed data toward the compilation of this paper.

LOCATION

The Saxet field is located 8 miles west of Corpus Christi and just south of Nueces Bay in the northern part of Nueces County, Texas (Fig. 1). The area is traversed by three highways, one concrete and two tar-topped, and now, by many hard-surfaced connecting and cross roads. One railroad passes through the field and another passes along its northeastern edge. The field is serviced by eight different pipe lines with tidewater terminals only 5–10 miles distant.

HISTORY

The history of the Saxet field is a combination of a series of new discoveries, most of which came at a time when the field no longer appeared to hold possibilities of additional production. The discovery of gas in the old White Point field, just across Nueces Bay north of what is now the Saxet field, led the Pioneer Oil Company, a local concern, to commence the drilling of its Dunn No. 1 on September 23, 1915 (Fig. 2). This well encountered a gas sand from 2,624 to 2,666 feet but the operators were advised that chances of oil production were so excellent that the well should be carried deeper. An oil sand was reported from 3,181 to 3,198 feet. Six-inch liner was set but the well made only salt water upon a completion attempt and was finally abandoned. No further drilling occurred until the Pioneer drilled its Meaney No. 1 which blew out from a shallow depth.

The Saxet Gas Company of Texas was organized to supply gas for the city of Corpus Christi, and on January 18, 1923, completed its Dunn No. 1 as a commercial gas well at a total depth of 2,408 feet

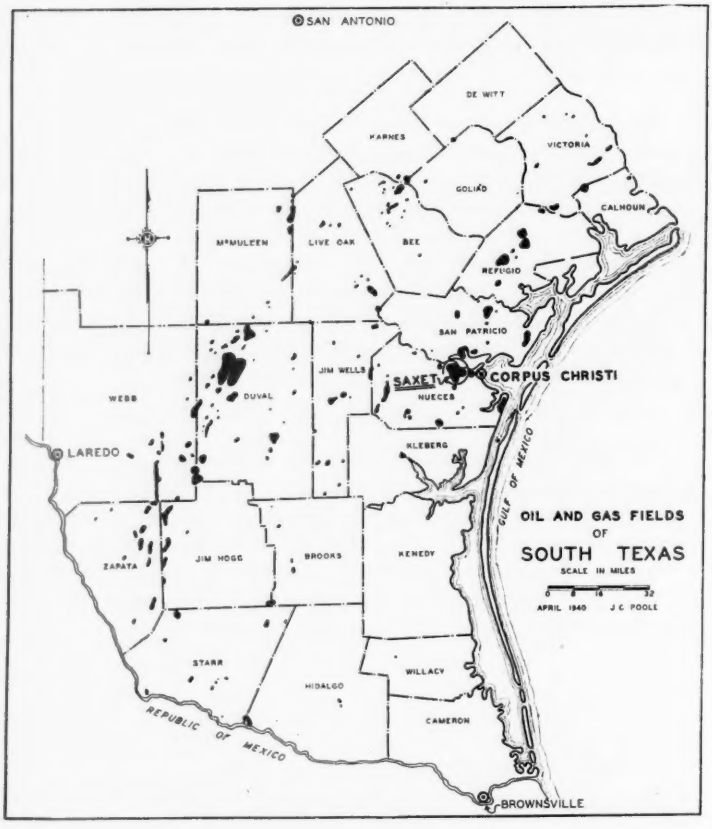

FIG. 1.—Map of oil and gas fields of South Texas.

(Fig. 2). This well is outside the limits of oil production as far as is known at present. The company drilled a number of wells during the ensuing 7 years which either produced gas or were failures.

On August 9, 1930, the Saxet Gas Company completed its Dunn No. 6 as an oil well at a total depth of 4,300 feet (Fig. 2). Thus, the discovery oil well is located on the extreme eastward extent of the

field as it is now known. The discovery well produced a total of 1,440 barrels of oil before going dead but the Saxet Gas Company in the meantime had recompleted its Dunn No. 2 as an oil well so that oil production has been unbroken since that time. In 1932 the discovery oil well was deepened to 6,713 feet but no additional production was encountered and the well was plugged back and recompleted in the

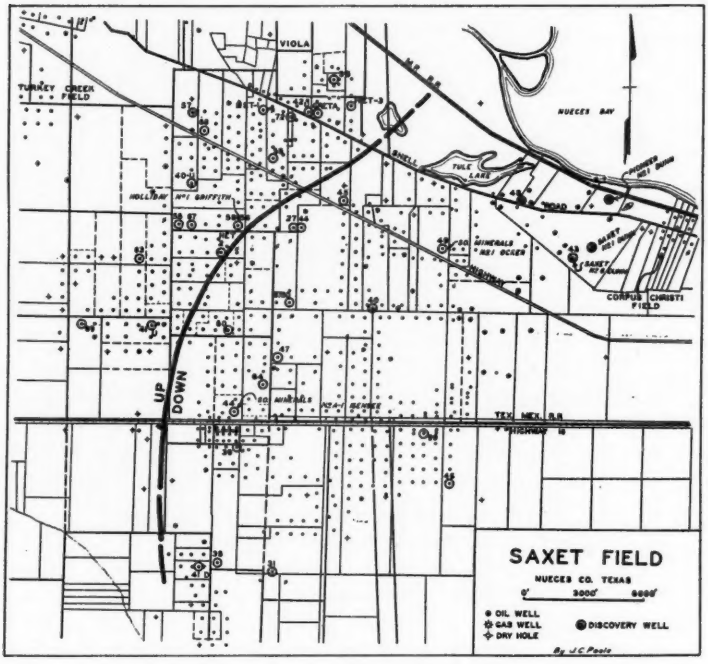

FIG. 2.—Discovery wells for various sands in Saxet field.

4,300-foot sand. Again, production was mostly water and the well was finally plugged back and completed from a shallow gas sand.

Following the oil showing made by the Dunn No. 6, and later, the Dunn No. 2, and the westward extension to gas production, considerable interest in the field was aroused and W. F. Morgan, of San Antonio, Texas, leased almost the entire area in which the main Saxet field now lies.

During the next several years, development was seriously retarded by a series of blow-outs which discouraged other operators from enter-

ing the field. It was also at about this time that 10-cent oil made it unprofitable for operators to risk their money searching for production. Furthermore, the class of production obtained in the Saxet field during this time did not encourage exploration to any great extent.

However, on December 31, 1930, the Houston Oil Company of Texas completed its Hunter No. 1 as an oil well with a high gas-oil ratio for the discovery well in the 4,000-foot sand, although Saxet's Donnigan No. 1, which was completed as a gas well from this sand on July 11, 1930, produced one barrel of 22.5° gravity oil daily. In September, 1931, the Gulf Coast Oil Company of Texas completed its Maggie Harrell No. 1 from the 4,500-foot sand. This well, although it made more water than oil on completion, produced a total of 179,000 barrels of oil before being abandoned.

The year 1932 saw four new sands discovered. The Oso Drillers of Texas completed its Roark No. 3 as a gas well spraying 40 barrels of 25° gravity oil daily from the 4,800-foot sand on October 4, 1932. Also in October, the Houston Oil Company completed its Harrell No. A-2 in the 4,400-foot sand. All these discoveries were on the downthrown side of the major fault. On the upthrown side (Fig. 2), the Houston Oil Company completed its McGregor No. 1 in the 4,200-foot sand in March, 1932. (Discovery wells are indicated in Figure 2 by circles with the first two numbers indicating the depth of the sand, and *U* or *D* to designate the side of the fault in cases of duplication.) In June, 1932, the Violet Oil Company of Texas completed its Belk No. 1 as a 300-barrel well. This well attracted sufficient attention to cause the drilling of eight wells before interest again lagged.

In studying the core records of all of these earlier wells, it is found that the customary description for either oil or gas sands lists them as "tasting salty." A common core record from above the various water levels as now known, reads "oil and salt water sand" or "gas and salt water sand." Occasionally, someone would fail to taste the sand and by depending upon the odor and appearance, set pipe and complete an oil well. The salty taste of the sands, coupled with the fact that the wells did make either considerable water or gas on completion, led to the general opinion that the Saxet field would probably be of little value from the standpoint of oil production. However, it was, of course, considered good gas property, a fact which led the Southern Alkali Corporation of Delaware to acquire a great many of the leases, holding them as a fuel reserve for their alkali plant located at Corpus Christi, Texas. It was to develop certain of these leases that the Southern Minerals Corporation of Delaware was formed.

Though the 4,800-foot sand had already been discovered by the

Oso Drillers in 1932, it was not until Southern Minerals completed its Ocker No. 1 in 1934 that general development began and twelve good oil wells were completed.

In 1935 the field was extended to the town of Clarkwood by the Texon Royalty Company of Texas which completed its Kocurek No. 1 in the 4,800-foot sand. This major extension led to considerable development in the area immediately north and east of Clarkwood, because it had become apparent that wells completed in the 4,800-foot sand were definitely commercial even though the sand itself rarely exceeded 6 feet in thickness.

The 4,400-foot sand had been discovered in 1932 by the Houston Oil Company, but it was again the Southern Minerals Corporation which focused attention on it with the completion of the Isensee No. A-1 in November, 1935.

On the upthrown side of the major fault, A. F. Holliday, an independent operator, completed his Griffith No. 1 in July, 1935, as a distillate and gas producer from the 5,600-foot sand. In September, 1935, Holliday completed his Smith No. A-2 as a distillate well from the 5,800-foot sand. This well was producing from above what was later found to be the oil zone for the 5,800-foot sand.

Holliday's Griffith No. 1 was deepened to the 5,800-foot sand and on April 5, 1936, completed as an oil well of such potentiality as to result in one of the largest and most spectacular drilling campaigns experienced in South Texas, despite proration and a relatively low price for oil. Oil from the 5,800-foot sand averaged around 38° gravity, was of excellent quality, was in great demand, and brought a considerably higher price than the lower-gravity oil which the field had previously produced.

Since that time, both deeper and shallower sands on both sides of the major fault have been discovered and the field has been extended in all directions until now approximately 9,100 acres can be considered proved. To date there are fifteen more or less regularly developed sands and some fifteen erratic sands, making a total of thirty in all, which will produce commercial oil or distillate.

The last important development was on the downthrown side of the fault when the Richardson Petroleum Company's Cain and Sechrist No. 24 was completed in October, 1938, producing 175 barrels of 55° gravity distillate through a 3/16-inch choke. In this well 10¾-inch surface casing was set at 656 feet and the well was drilled to 9,925 feet. Drill pipe was stuck at 9,898 feet when the well attempted to blow out and production is coming through drill pipe. On the upthrown side of the major fault, Richardson deepened his Maggie Harrell No. 3 to a

TABLE I

Discovery Well Data for Different Sands

Sand Name	*Side of Fault*	*Operator*	*Farm*	*Well No.*	*Discovery Date*	*I.P. in Barrels*	*Choke*	*Depth (Feet)*	*Degrees Gravity*
2,700-foot	D	Gulf Coast	Bessie Elder	2	7/ 2/32	100		2,731–42	22
3,100-foot	D	Clarkwood Oil	Buckholt	1	1/ 5/36	200[1]	9/32	3,155–76	22
3,800-foot	D	Gilcrease	Sullivan	3	5/22/37	112[2]	Pump	3,845–48	27
3,900-foot	D	Texon	McElroy	2	2/ 4/36	99	1/8	3,997–4,002	27
4,000-foot	D	Houston	Hunter	1	12/31/30	200		4,046–59	22.6
4,000-foot	U	Howell	Hutchins	5	7/ 8/37	40	1/8	3,996–4,004	23
4,100-foot	D	Bryant & Howell	Kocurek	A-1	2/12/37	250[1]		4,118–23	26
4,100-foot[3]	U	Morgan Gulf	Morgan	A-1	3/20/36	156	5/32	4,072–85	23
4,200-foot[4]	U	Houston	McGregor	1	3/ 3/32	150		4,254–66	25
4,300-foot	D	Saxet Gas	Dunn	6	8/ 9/30	120[5]		4,292–4,300	23.6
4,400-foot[6]	D	Houston	Harrell	A-2	9/ 1/32	150	3/16	4,403–14	26–29
4,500-foot	D	Gulf Coast	Maggie Harrell	1	9/ 7/31	143	5/16	4,543–64	27
4,600-foot	D	Richardson	Hoelscher	1	11/20/36	185	1/2	4,571–74	26
4,700-foot	D	Houston	L. Harrell	6	9/ 9/37	80	1/8	4,715–23	27
4,800-foot[7]	D	Southern Minerals	Ocker	1	6/ 2/34	600	1/4	4,865–71	24
Heterostigina 1	U	J. K. Culton	Sagarin	2	6/20/35	155	5/32	4,725–36	24.1
Heterostigina 2	U	Gulf Port	Bliss	2	10/22/32	200	3/16	4,751–59	26
Heterostigina 3	D	Richardson	Perkins-LaGasse	13	1/30/40	72[8]	1/4	5,156–64	
Heterostigina 3	U	Pan American	Solar-Sevier	1	12/31/36	155	5/32	4,837–42	26
Greta	U	Violet & Hilligest	Belk	1	6/19/32	300	1/4	4,867–75	26
5,300-foot	U	Glasscock	Johns	1	8/24/37	240	1/4	5,299–5,308	32
5,500-foot	U	Hiawatha	Griffith	7	6/21/37	115	5/32	5,533–43	34
5,600-foot	U	Holliday	Griffith	1	7/ 6/35	25[9]	1/8	5,598–5,602	Distillate
5,700-foot	U	Paul Benedum	Page	1	6/30/37	60[10]	5/32	5,753–58	
5,750-foot	D	Richardson Pet.	Perkins-LaGasse	6	9/15/37	188	1/8	5,810–15	52
5,800-foot[11]	U	Holliday	Griffith	1	4/ 5/36	179	1/8	5,818–28	38
6,000-foot[12]	D	Barnsdall	Humphrey	A-7	8/26/38	148	1/8	6,000–10	28
6,300-foot	U	Chapman Minerals	Morgan-Clark	4	9/10/36	128[10]		6,286–94	59
6,500-foot[13]	D	Western Gulf	Isensee	4	4/24/38	72	1/8	6,464–67	48.6
6,600-foot	U	Proved by test. No well yet							
6,700-foot	U	Hiawatha	Griffith	6	12/28/36	137	7/64	6,744–59	48
6,800-foot	U	Bentex	Harmon	5	5/ 1/37	108	1/8	5,772–76	38.5
6,900-foot	U	Republic	Ordner	3	2/12/33	128	1/8	6,898–6,912	41
7,200-foot	U	Richardson	Erigan	2	6/ 1/38	136[10]	5/32	7,315–25	56
9,900-foot	D	Richardson	Cain & Sechrist	24	10/12/38	175[10]		9,898–9,925	55

[1] 50 per cent salt water.
[2] 112 barrels oil and 40 per cent salt water.
[3] Equivalent of 4,400-foot sand of downthrown side.
[4] Equivalent of 4,500-foot sand of downthrown side.
[5] 120 barrels oil and 800 barrels salt water.
[6] Active development started with Southern Minerals' completion of Isensee No. A-1 on 11-19-35, producing 664 barrels daily through 5/16-inch choke from 4,389–4,403 feet.
[7] Oso Drillers Roark No. 3, completed 10-4-32, as gas well spraying 40 barrels daily oil from 4,864–67 feet. Recompleted 3-4-33, at a total depth of 4,886 feet, producing 100 barrels daily oil and 95 per cent salt water.
[8] 72 barrels oil and 15 per cent salt water.
[9] 25 barrels gasoline.
[10] Distillate.
[11] Holliday Smith, No. A-2, completed 9-16-35, producing 20 barrels through 1/8-inch choke, through perforations from 5,785 to 5,792 feet. Well made gasoline.
[12] Equivalent to 5,500-foot sand of upthrown side.
[13] Equivalent to 5,800-foot sand of upthrown side.

total depth of 10,024 feet, at which point liner was set, but the well was abandoned after several attempts to complete it had failed. During the past year, the Hiawatha Oil and Gas Company of Delaware drilled its Smith No. B-8 to a total depth of 10,892 feet where drill pipe was stuck and the well was finally abandoned. The three "10,000-foot" tests are shown by large circles in Figure 10.

PHYSIOGRAPHY

From a physiographic standpoint, the Saxet field was represented by a plain rising gently toward the west and broken only on the north by ravines leading into Nueces Bay. Since the development of oil and gas production in Saxet, however, the plain is now interrupted by large craters which are often referred to as the "Saxet range." As previously stated, Price[7] pointed out in his paper on diastrophism in the Corpus Christi area argument for topographic expression of a subsurface nose plunging eastward. He also indicated what he called the "fault scarp" which would coincide rather closely in spots with the projected surface trace of the major fault which divides the field (Fig. 2). Deussen,[8] in his report on the "Geology of the Coastal Plain of Texas West of Brazos River," noted the increased slope of the coastal plain in that area just north and west of the town of Clarkwood, and also noted the constriction of Nueces Bay between what is now the Saxet and White Point fields.

The area has been, in the main, under cultivation for many years and only locally are wooded sections found.

STRATIGRAPHY

The surface formation was originally Beaumont but is now partly covered by fragments of older formations which have been blown out of various wild wells. Minor blow-outs (Fig. 3) became so common as to arouse no comment and were taken as a matter of course in the development of the field.

In dealing with the stratigraphy of Saxet, it becomes readily apparent that the field must be divided for all further discussion into essentially two separate and distinct pools. This is necessitated by the major fault heretofore mentioned which is downthrown on the southeast and which effectively cuts the field into two parts. The following divisions apply to that portion of the field located on the downthrown side of the major fault.

Due to the non-marine character and lack of electrical-log control,

[7] W. Armstrong Price, *op. cit.*, pp. 949–51.

[8] Alexander Deussen, *op. cit.*, pp. 132, 134–35.

[11] Equivalent to 5,800-foot sand of upthrown side.

little information is available on the part of the section above the Lagarto-Oakville. It is known, however, that the section from the surface to a depth of 2,000 feet is Beaumont, Lissie, and Goliad and is made up of a series of sands and shales with sand in predominance except at the surface. In most other parts of South Texas, the Lissie sands are fresh-

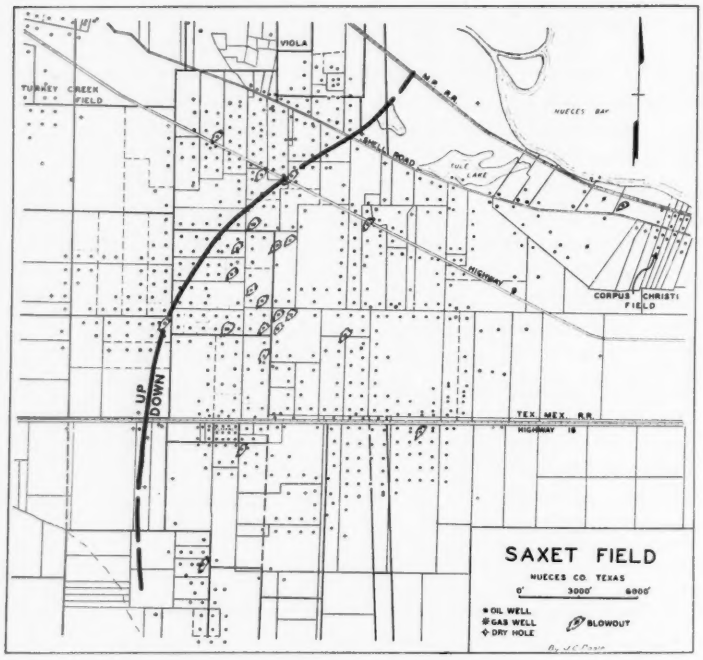

FIG. 3.—Blow-outs of Saxet field.

water bearing. However, in the Corpus Christi and Saxet areas, even the earlier wells found these sand bodies carrying salt water and sulphur water. At the present time these shallow sands are highly charged with gas originating from deeper sands and have been responsible for a good many of the lesser and more recent blow-outs.

The Lagarto-Oakville section (Fig. 4), which is considered to occur between the depths of 2,000 and 3,750 feet, contains most of the gas sands of early Saxet development. The uppermost part of the section, or probably the Lagarto, is predominantly shale with a series of sand lenses, and it was from one of these sand lenses that the discovery gas well in Saxet was completed. These sands can be seen in Figure 10

and are erratic in nature but still were consistent enough to be used as a basis of contouring the Saxet field prior to the advent of deeper drilling. The Oakville sand series occupies, roughly, that section between 3,150 and 3,750 feet. This section is predominantly sand and has three members highly charged with gas. The sand is relatively coarse grained and somewhat ashy in character. The shales grade from tan to rust in color. As far as the field is concerned, the Oakville sand series is continuous and can be used for purposes of contouring. On the downthrown side of the fault, there is ample electric-log control to show both these sand beds and the Lagarto sands above. A few wells in the field have produced oil from the 3,100-foot sand which is the top member of the Oakville sand series.

The section from 3,750 to approximately 4,800 feet is considered Catahoula and, as represented in the Saxet field, is predominantly sand or sandy shale becoming more sandy toward the east. The Catahoula sand series contains the 3,800-, 3,900-, 4,000- (Corpus Christi pay sand), 4,300-, 4,400-, 4,500-, 4,600-, and 4,700-foot oil sands of the downthrown side of the major fault, and the 4,000-, 4,100-, and 4,200-foot sands of the upthrown side. Of these sands, the most important from the standpoint of production are the 4,400-, 4,500-, and 4,700-foot sands. Examination of cores of the 4,500-foot sand shows it to have certain characteristics of deltaic deposition, that is, what appears to be top-set, fore-set and bottom-set beds. What appears to be the top-set bed is, however, made up of fine-grained shaly sand, whereas the other beds are of coarse-grained sands. This fact suggests cross bedding but fails to explain the regular 30° dips of the "fore-set beds." The 4,000-foot sand is known principally as a gas producer as far as the Saxet field is concerned.

The Marine zone of the middle Oligocene is represented from approximately 4,800 to 5,000 feet by the *Discorbis* zone which is predominantly marine shale but in which occurs the 4,800-foot producing zone of the downthrown side of the fault, and from 5,000 to 5,200 feet by the *Heterostegina* zone. The Marine shale between the 4,800-foot sand and the top of the *Heterostegina* zone is referred to as the "Marine wedge." There are three producing sand phases in the broken top of the *Heterostegina* zone (Fig. 4), which are called a part of the Greta sand series, but from a productive standpoint will be referred to as *Heterostigina* 1, *Heterostigina* 2, and *Heterostigina* 3.

Formations below 5,200 feet are, for the sake of convenience, classified as Frio in age. However, on the upthrown side of the major fault, the Hiawatha Oil and Gas Company drilled its Smith No. B-8 to a total depth of 10,892 feet, encountering the first *Textularia warreni* at

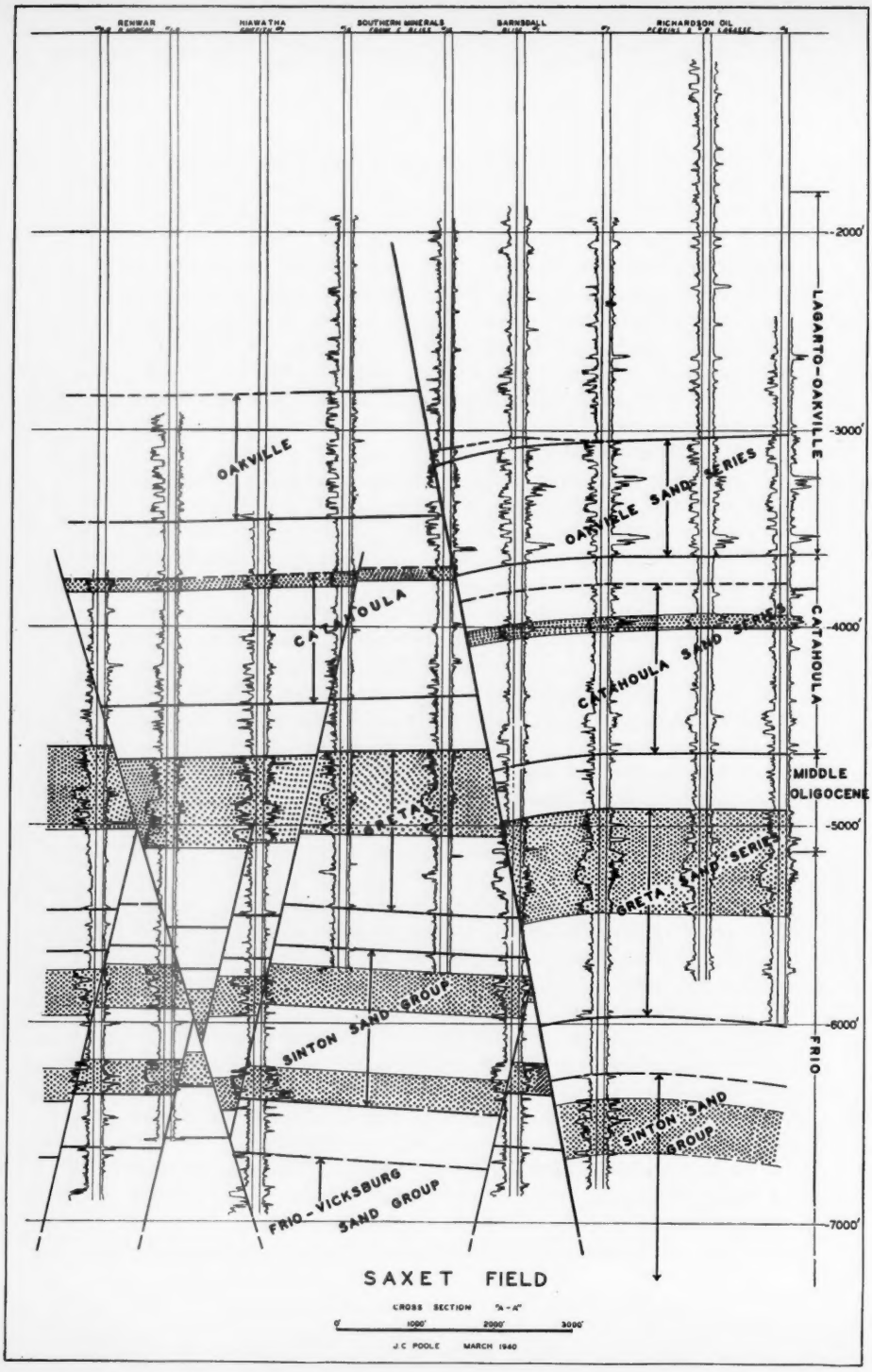

FIG. 4.—Cross section *AA* showing complex faulting and divisions of sand series and groups with relation to geological time divisions.

9,925 feet, thereby definitely penetrating the Vicksburg formation of the Oligocene. D. F. Newell[9] states that the beds from 9,035 to 9,925 feet contain a calcareous fauna, none of which is diagnostically Vicksburg, and believes that it might possibly be equivalent in time to the Hackberry wedge.[10] He also considers that the well was still in the Vicksburg formation at its total depth. The electric log of Hiawatha Smith No. B-8 showed well developed sands to 9,920 feet but was not run below 10,002 feet. According to the drilling record, the section from there on to total depth was reported as shales.

Due to excellent correlations afforded in the Gulf Coast area by electrical well-logging devices, the South Texas coastal section is herein divided into various sand series and groups which do not completely coincide with divisions of geological time (Fig. 4). Thus, the Greta sand series is partly in the *Heterostegina* zone and partly in the so-called Frio. The time divisions, Recent, Pleistocene, Pliocene, and Miocene are not noted on cross section *AA* (Fig. 4) because they are not represented by Marine beds in this area. Figure 4 shows the division of the various sand series which are readily apparent through the use of electrical logs and while certain of the sand series do not appear justified in this localized field cross section, they are immediately apparent on a regional-dip cross section.

GEOLOGY AND STRUCTURE

Though credit for the discovery of the Saxet field must necessarily go to trend play and local enthusiasm, the location of the discovery oil well had as its basis surface and subsurface geological interpretation.[11] Evidences of surface structure have been discussed.

From a subsurface standpoint, the amount of structural uplift in the Saxet field is a matter of conjecture. The Saxet and White Point fields definitely interrupt the general dip into the Rio Grande embayment but Saxet appears to be only about 125 feet higher than normal on the Greta sand top and 180 feet higher than normal on the 5,800-foot sand top. Even these figures are conjectures. It is quite possible that there actually was no structural uplift and the structure as it now exists merely represents certain areas which failed to subside along with the surrounding country. An attempt to determine the total closure represented by the field is made difficult by the many faults.

The most outstanding feature of the field is the major fault (Figs. 4 and 5). Definite data as to how high in the section this fault is effec-

[9] D. F. Newell, Phillips Petroleum Company, personal communication.

[10] M. M. Kornfeld, "Hackberry Foraminiferal Zonation at Starks Field, Calcasieu Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 12 (December, 1939), pp. 1835–36.

[11] W. Armstrong Price, *op. cit.*, p. 1351.

tive are lacking; however, from a study of electrical logs, beds as high as 1,400 feet below the surface are definitely displaced. Furthermore a constriction of Nueces Bay on the north and the sudden increase in the dip of the coastal plain just north of Clarkwood strongly suggest that the fault reached the surface or has seriously affected surface topography. The fault plane hades east and southeast 27°, as is represented by Figure 4. There is, however, considerable evidence in the upper beds between 2,500 feet and the surface that the hade increases, as is indicated in Figure 10. The maximum throw of the fault on the 4,000-foot sand is 350 feet, and on the 5,800-foot sand, 675 feet. The amount of throw, however, decreases both northeast and south as compensating faults become effective, and it is believed that the major fault may die out entirely toward the northeast. From electrical log records, it appears that the zone of fault movement is, at most, only a few feet in width (see cross sections) because sharply defined short sections exist. By this, it is meant that if there was a wide zone of fault movement, the electrical logs would show an indefinite section over a vertical distance of 200 or 300 feet or more and this is decidedly not the fact. Electrical logs do indicate possible mineralization in the Oakville sand series. In 1933 and prior to the advent of widespread use of electrical well logging in this country, A. E. Getzendaner[12] discussed this fault which he based on paleontological data.

With the beginning of the 5,800-foot sand development, it appeared that the section on the upthrown side of the major fault was either exceptionally erratic or that there were several minor faults. Opinion of geologists was at first divided but deeper drilling definitely proved the existence of a series of faults which can be located either by cross sections or a close study of short sections in offset wells (Fig. 4). The cross-section method is chosen because it presents the over-all picture. Further proof of the series of small faults exists in the fact that most of the sands (see cross sections) appear continuous throughout the field.

A map contoured on the top of the 4,000-foot sand, or Corpus Christi pay sand, is represented by Figure 5. The productive area of this sand, from a standpoint of either oil or gas, is larger than that of any other in the field. Only the thinness of the zone of oil saturation and the accompanying difficulty of completing wells keep it from being a major oil producer in the Saxet field. On the 4,000-foot sand contour map, it will be noted that there are eight definite faults other than the major fault. Three of these faults on the upthrown side of the major fault have their downthrown sides on the east, while the other is

[12] A. E. Getzendaner, *op. cit.*, pp. 527–28.

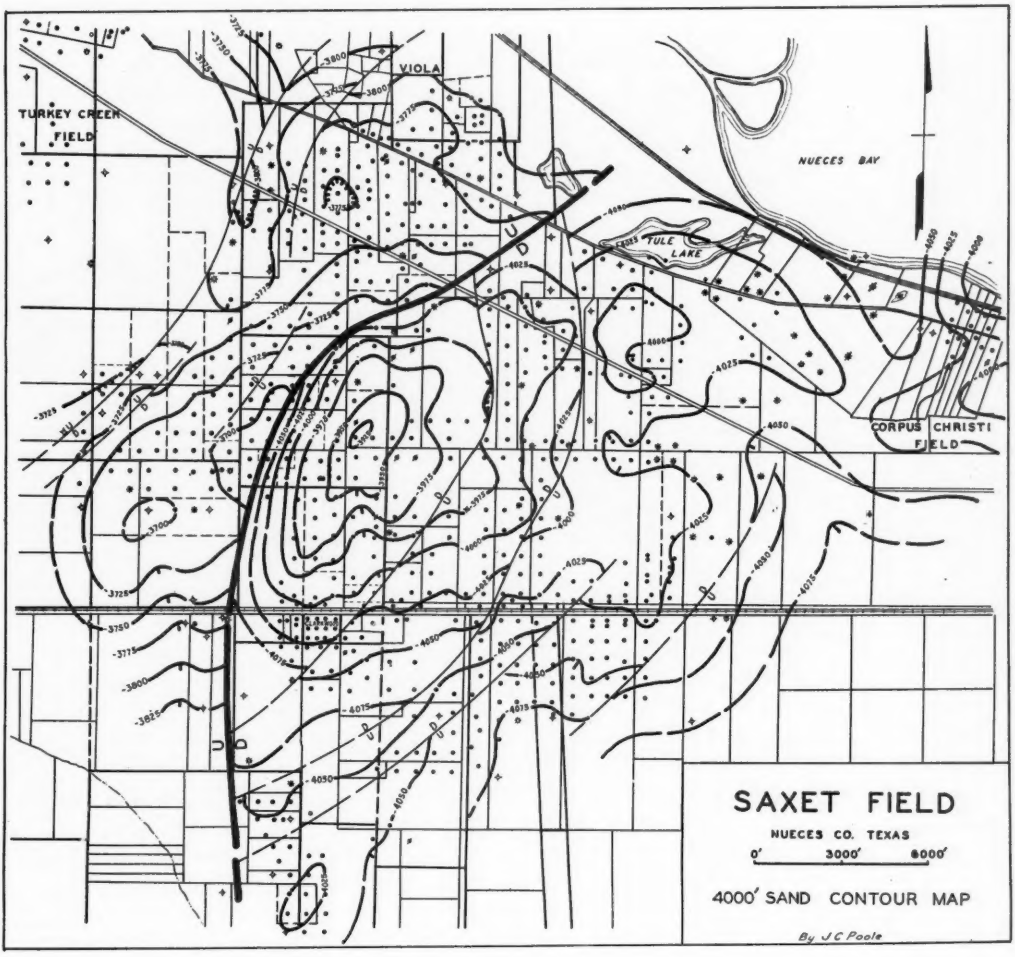

FIG. 5.—Contour map based on top of 4,000-foot sand.

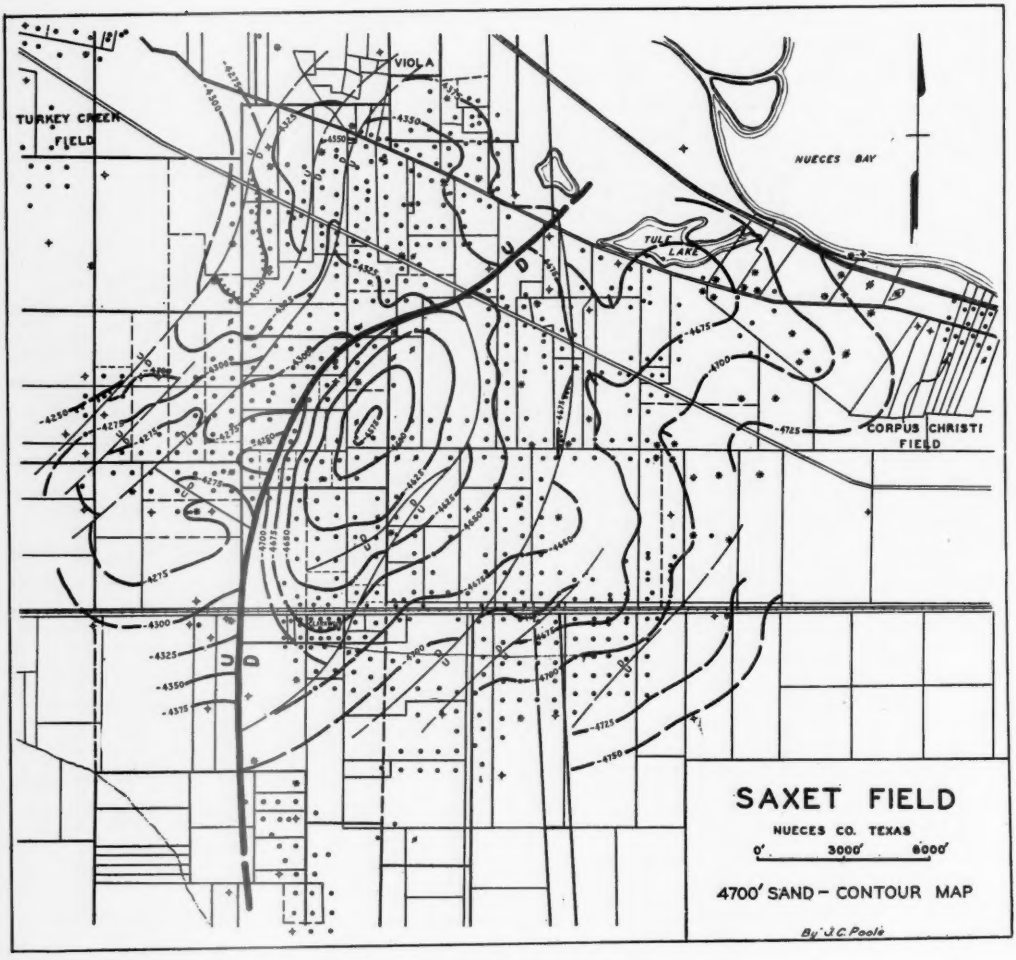

FIG. 6.—Contour map based on top of 4,700-foot sand.

downthrown on the west. These faults with one exception are of relatively small throw. The small faults on the downthrown side of the major fault, however, are all of compensating nature and are downthrown on the west, forming a step-graben. Of especial interest is the rapid dip of formations into the major fault on the downthrown side and the fact that the highest part of the structure on the downthrown side lies immediately within the bend of the major fault. A continuation of this latter condition southeast and across the compensating faults is represented by a gentle, faulted nose, the axis of which is, roughly, at right angles to the trace of the major fault at the vertex of its curvature.

A map based on the top of the 4,700-foot sand (Fig. 6) shows essentially the same conditions as the one contoured on the 4,000-foot sand with the exception of a cross fault and an extension of one of the small faults on the upthrown side of the major fault. Attention is called to the fact that the minor faults curve in exactly opposite directions to the major fault. Also, it will be noted that the amount of closure on the downthrown side of the major fault appears to be less than is shown on the 4,000-foot sand contour map. This apparent change in amount of closure actually does not exist but results from the fault plane having moved eastward with depth. The 4,700-foot sand contour map also shows an additional small fault on the downthrown side of the major fault which has apparently split off from one of the faults shown by the previous map.

A contour map based on the top of the 5,800-foot sand (Fig. 7) shows the development of a veritable maze of faults on the upthrown side of the major fault and an increase in the magnitude of all faults. This influx of faulting is first noted at the base of the thickest member of the Greta sand series, and due to the repetition of this condition in other South Texas fields it is evident that the Greta sand represents a widespread unconformity, which will hereafter be referred to as the "Greta unconformity."

Of the three contour maps, best control is afforded for the 4,000-foot and 4,700-foot horizons. The 4,000-foot sand contour map is somewhat lacking in control on the upthrown side of the major fault because many of the operators did not run electric logs above 4,000 feet. On the 4,700-foot sand map, much control is lacking east and southeast of the town of Clarkwood because most of that development is in the 4,400- and 4,500-foot sands, and thus electric logs were not run deep enough. Control for the 5,800-foot sand map on the downthrown side of the major fault is scarce and can best be seen by referring to Figure 8, on which all wells reaching the 5,800-foot sand are

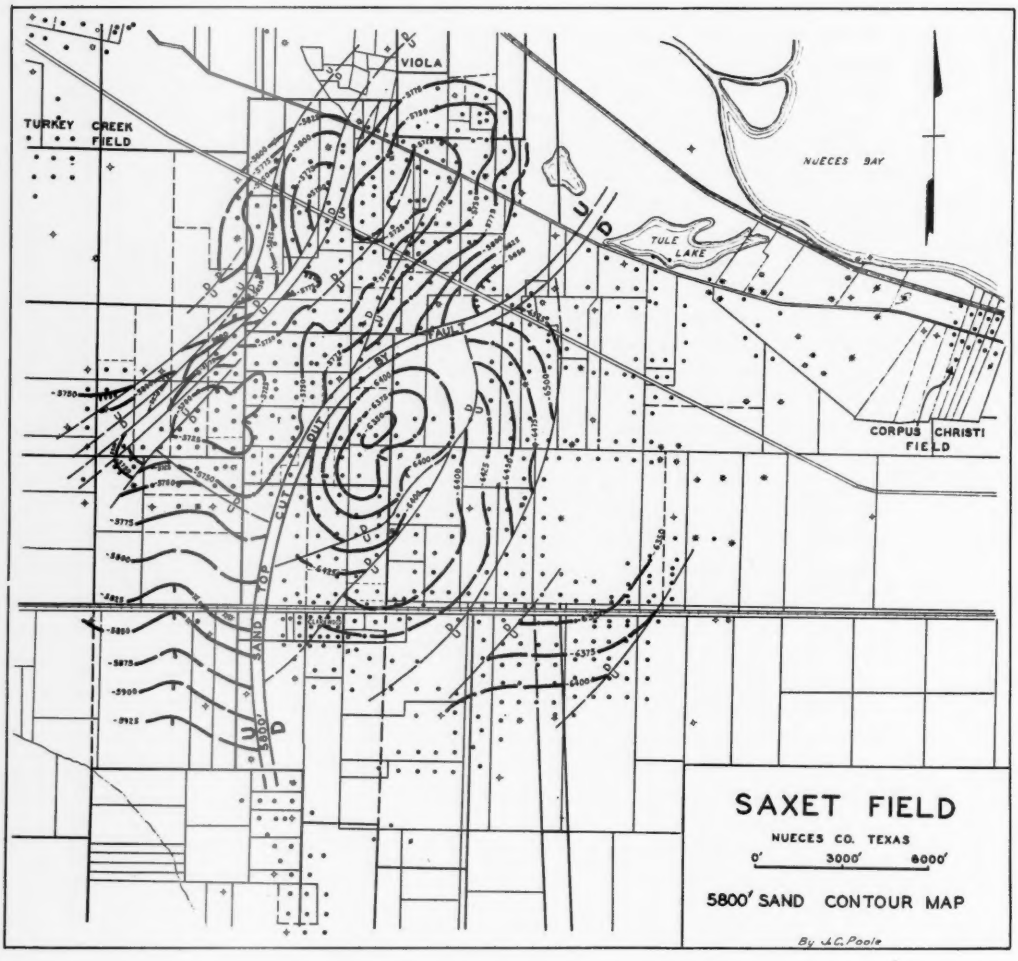

FIG. 7.—Contour map based on top of 5,800-foot sand.

circled. It has been considered best not to show operators' names, fee owners' names, well numbers, subsurface datum points or many twinned wells, because such lettering and figures would necessarily have to be so small as not to be legible after having been reduced.

From a study of the contour maps, it will be noted that none of the faults traverses that portion of the field lying immediately south of the townsite of Viola. Two of the faults go to the top of the structure (Fig. 7) but appear to die out before crossing it. It is also noted that these faults do not cut the younger beds.

From the standpoint of isopach maps, using the intervals between the *Heterostigina* 1 sand and the 5,800-foot sand (Fig. 8) and between the 4,000-foot sand and the 6,300-foot sand (Fig. 9), it will be noted that the greater shortening of section took place in that area just south of Viola as far as the upthrown side of the fault is concerned. Attention is called to the effect produced by faulting on the isopach maps, which is represented by long narrow areas of shortened section. The isopach map between the *Heterostigina* 1 sand and the 5,800-foot sand (Fig. 8) shows considerable shortening of section centering about 1½ miles east of Clarkwood. Attention is again called to the sparsity of control on the downthrown side of the fault, and it is believed that with further deep drilling, this portion of the isopach map will be considerably changed in character although the thinning will still be present. No isopach contours were drawn on the map between the 4,000-foot sand and the 6,300-foot sand on the downthrown side of the fault because control was almost wholly absent.

A series of isopach maps failed to show any major difference from these discussed save the map between the 4,000-foot sand and the 4,700-foot sand, which did not show anything definite, and that map between the 4,000-foot sand and the 6,900-foot sand, which shows additional shortening of section on the south end of that portion of the field on the upthrown side of the major fault. Indication of this shortening is shown by the isopach map between the 4,000-foot sand and the 6,300-foot sand (Fig. 9).

Cross section *AA* (Fig. 4), the alignment of which is shown in Figure 10, is drawn from northwest to southeast, beginning on the western side of the field and extending to the center. A study of the porosity and resistivity curves of electrical logs used in this section shows in detail the intricate faulting on the upthrown side of the field and has as its most interesting point the displacement of older faults by younger faults, which results in a graben for the upper beds, which is immediately underlain by horsts in the lower beds. Cross section *AA* has been entered in larger scale so readers of this paper will be

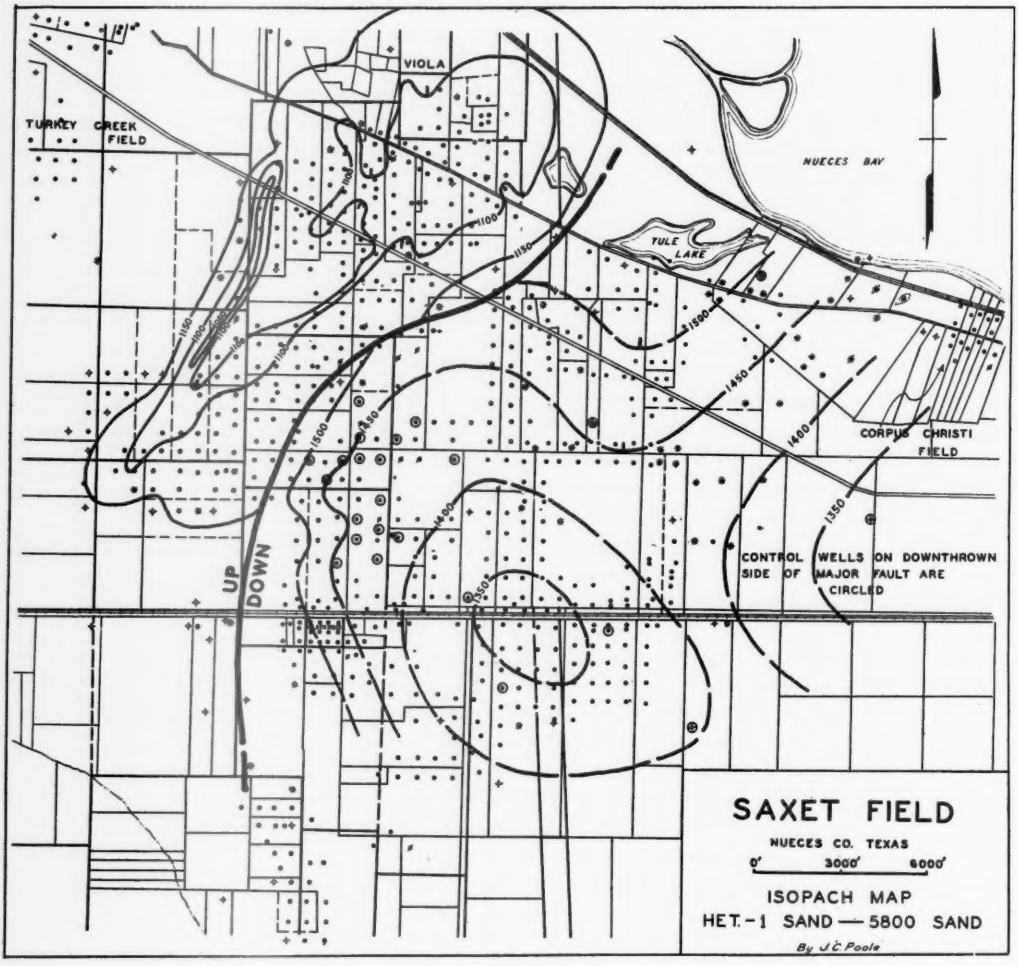

FIG. 8.—Isopach map of interval from top of *Heterostigina* 1 sand to top of 5,800-foot sand.

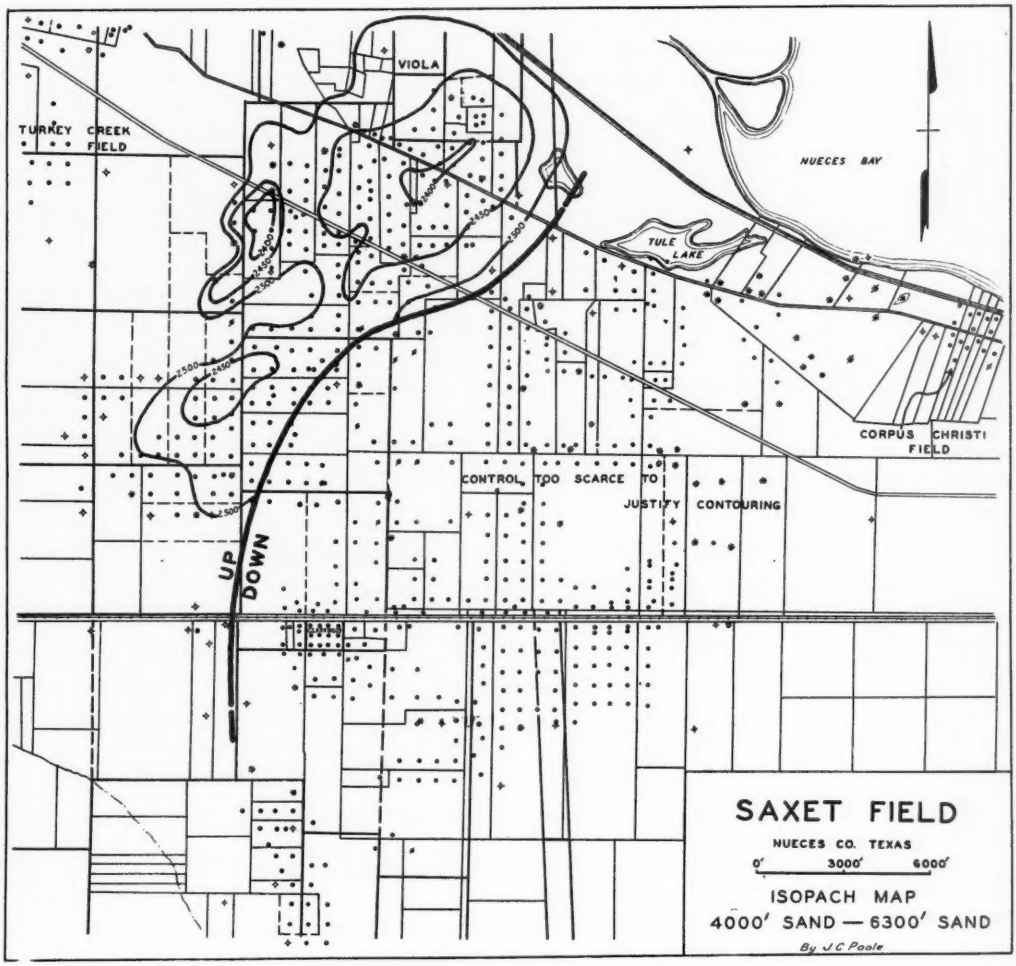

FIG. 9.—Isopach map of interval from top of 4,000-foot sand to top of 6,300-foot sand.

able to check the correlations of the writer. The relative ages of all of the faults can not be determined because of the lack of electrical-log control as far as the upper portion of the wells is concerned. The additional information afforded by the electrical-log record of the upper portion of these wells might very easily prove valuable in deeper drill-

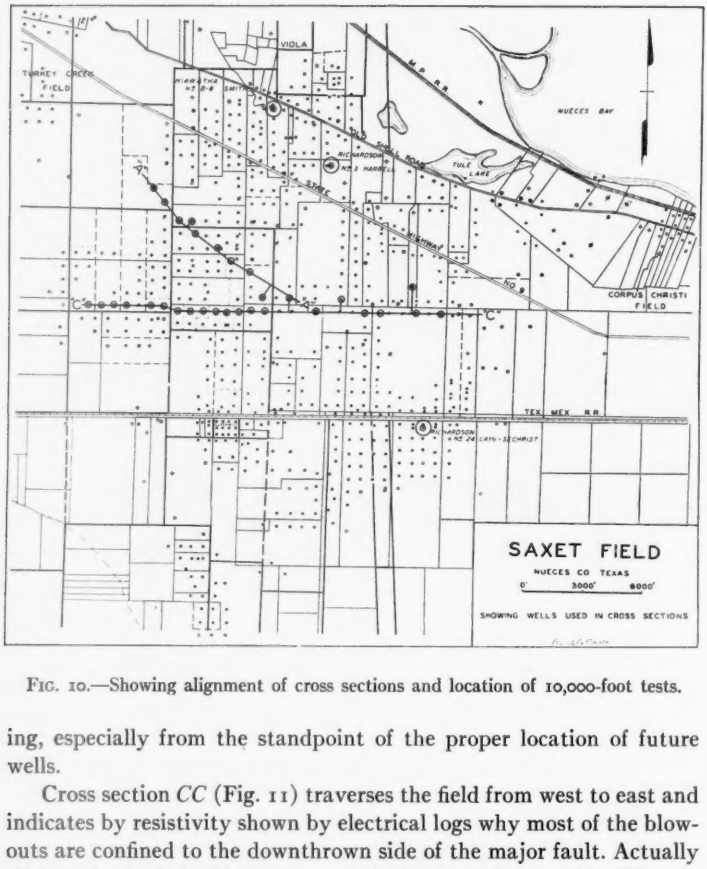

FIG. 10.—Showing alignment of cross sections and location of 10,000-foot tests.

ing, especially from the standpoint of the proper location of future wells.

Cross section *CC* (Fig. 11) traverses the field from west to east and indicates by resistivity shown by electrical logs why most of the blow-outs are confined to the downthrown side of the major fault. Actually all but three of the blow-outs are on the downthrown side (Fig. 3). It is apparent that in the highest part of the structure, as far as the upthrown side of the major fault is concerned, all of the beds are dipping away from the fault plane whereas on the downthrown side the highest part of the structure is away from the fault plane and the

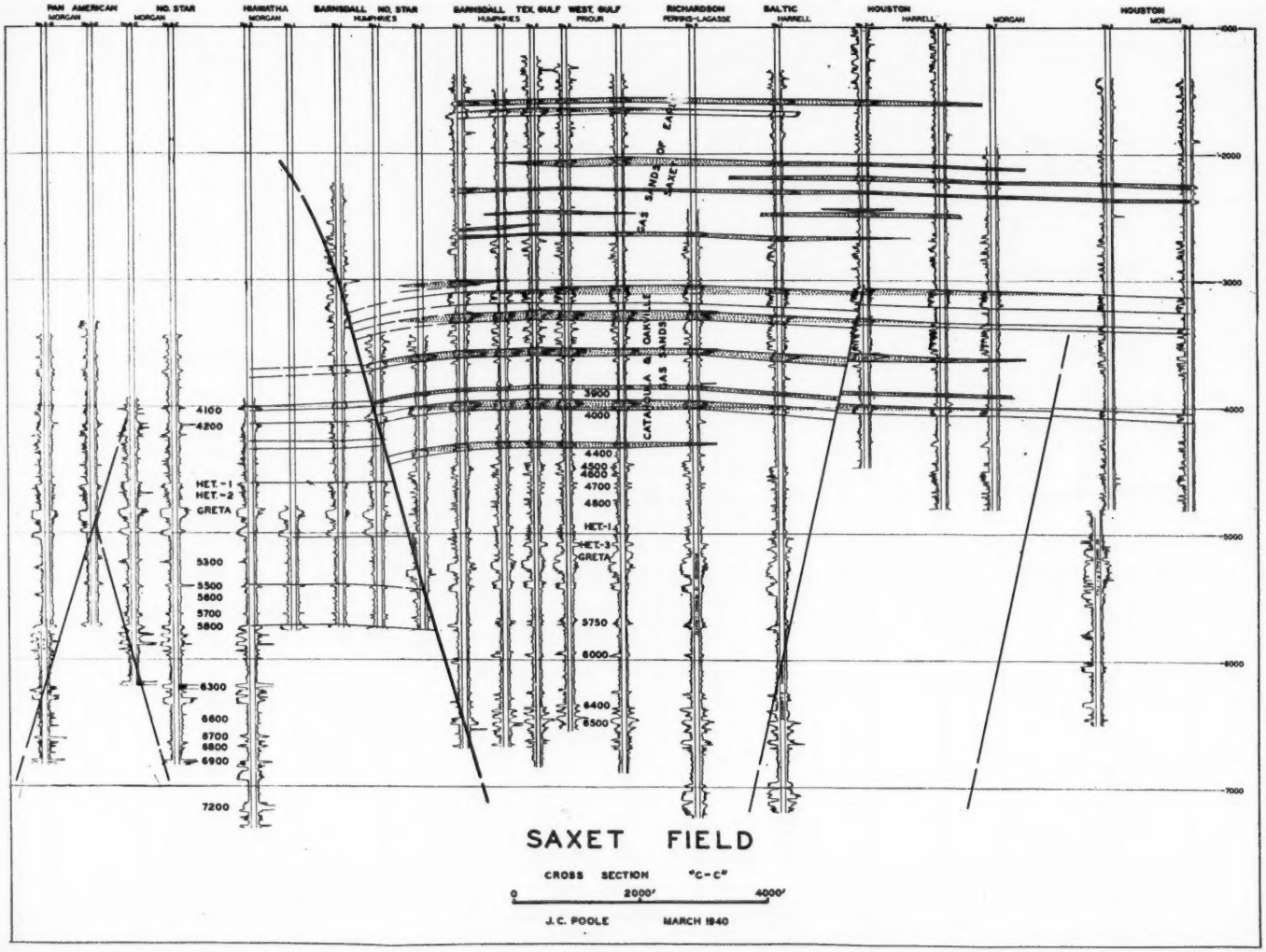

FIG. 11.—Cross section *CC* showing upper gas sands of downthrown side of major fault and the position of various oil and distillate sands.

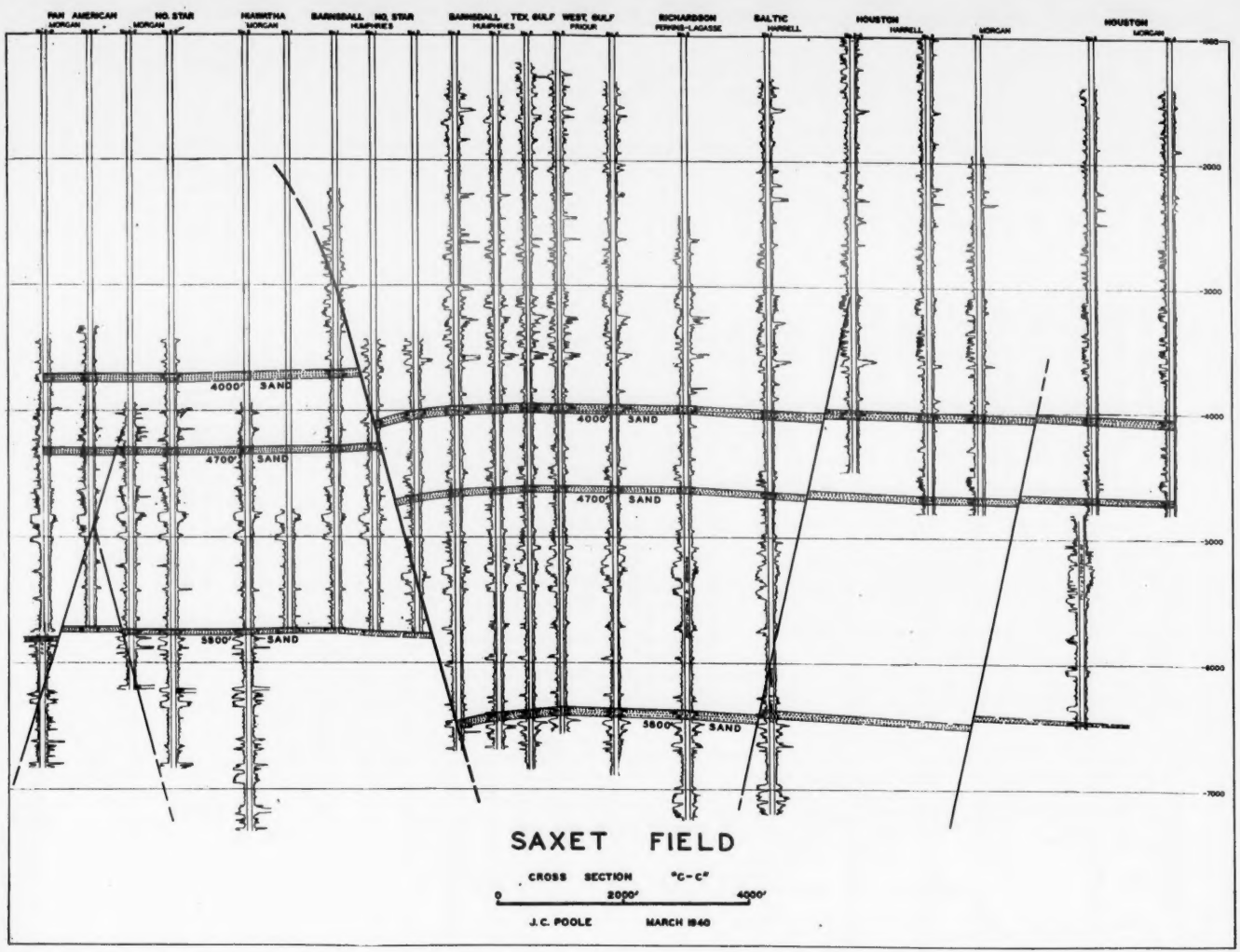

FIG. 12.—Cross section *CC* showing sands on which contour maps were drawn.

beds dip sharply into it. Therefore, any gas that may have migrated up along the major fault plane would naturally be trapped in those highly permeable and porous sands on the downthrown side of the field. This statement applies only to the Oakville, the Catahoula, and the top of the Greta sand series. The gas sands referred to have been dotted in on cross section *CC* (Fig. 11) for emphasis. The sand bodies dotted in Figure 12 represent the various horizons on which contour maps have been drawn. Figure 11 also shows the relative positions of the various producing sands in the field. Due to the many sands encountered, most are referred to only by their depth. However, the same sand in many wells produces at different depths because of being on different sides of the major fault. Therefore, in the Saxet field, naming sands by their depths alone is somewhat confusing and yet is, through necessity, the general practice.

It is noted from these cross sections that the amount of throw of all faults increases with depth. This is represented by a thickening of section on the downthrown side as the fault plane is approached. It is believed that the section away from the fault is not thinned by erosion but that continued movement along the fault plane during deposition accounts for most of the thickening near the fault plane. This condition is most notable in the Greta sand series and older beds, and the faults cutting the upper beds (younger faults) show little increase in throw.

It is further noted that there is considerable thickening of section into the major fault on the upthrown side with the thickening taking place largely in the dominant non-marine shale zone in the basal part of the Greta sand series.

In the older series of faults, movement apparently stopped during the deposition of the larger member of the Greta sand body. Cross section *CC* (Figs. 11 and 12) shows that the compensating faults on the downthrown side of the field have assumed greater magnitude by the time the 5,800-foot sand is reached.

It is impossible to show clearly with so few cross sections all of the intricate fault pattern shown by the contour map on the 5,800-foot sand (Fig. 7). However, the fault pattern as existing on all of the contour maps is determined by a total of twenty-four cross sections which are drawn at right angles to one another. A study of these cross sections, due to the accuracy of information shown by electrical logs in the coastal or "soft rock country," makes the intricate fault pattern quite clear. Due to the close spacing pattern (10 acres) existing in the field, certain of the cross sections have become locally valueless because of crooked holes. Considerable care had to be exercised in elimi-

FIG. 12.—Cross section *CC* showing sands on which contour maps were drawn.

nating these crooked holes. With wells spaced only 660 feet apart and being drilled to a depth of 5,800–6,900 feet, it is apparent that only 3° or 4° deviation from vertical would be sufficient to cause considerable confusion in an area of complex faulting such as is indicated on the upthrown side of the major fault by the 5,800-foot sand contour map.

From the cross sections shown, it is easy to understand why so many offset wells have to be completed in different sands because in some cases the producing zone of the offset well is cut out by a fault, or dropped too low to produce. During active development, the one saving factor in the Saxet field seemed to be that as long as an operator was willing to take cores and go deep enough, he was assured of completing a well somewhere.

From a study of various completions, it appears that faulting which occurred previously to the deposition of the *Heterostigina* sands has no effect on the water levels other than to drop the beds below said levels. There are indications, however, that the fault planes of these older faults are sufficiently impervious to control drainage. These older faults apparently die out toward the north (south of the townsite of Viola), allowing oil and gas to migrate around and fill the sands to a constant level.

The younger faulting which cuts the upper beds has had a very decided effect on the several water levels. This is noted in the various sands throughout both sides of the field. It is interesting to note that, from evidence at hand, there are no faults whose movement stopped in the Greta sand series on the downthrown side of the major fault.

Though there is some oil produced in the Greta sand and younger beds on the upthrown side of the fault, it appears to be of little consequence except in that dome-like portion of the structure immediately south of Viola and in the area just northwest of Clarkwood. These areas appear to be cut off from the rest of the upthrown side by structural closure and faulting and wherever this condition exists, production is had from the younger beds. Production is also found in sand lenses in the Catahoula sand series. Over a large portion of the upthrown side of the major fault, however, it appears that either no oil was accumulated in these upper beds or, if so, the oil has been drained out into the beds on the downthrown side. It is believed that this latter theory may account for so many of the younger sands producing oil on the downthrown side of the field and would particularly account for production in the 4,000-foot or Corpus Christi pay sand which virtually coincides at the fault plane with the 4,400-foot sand as represented on the upthrown side of the field.

From a productive standpoint, the 4,500-foot sand is a very unusual one in that in one well it appears to have a 20-foot vertical zone of effective saturation in which oil wells can be completed, whereas in the offsets the sand is still saturated but nothing more than gas and salt water can be produced. In several wells, cores of the sand saturated with oil throughout a vertical zone in excess of 50 feet have been recorded. This same condition is true in the 4,400-foot sand over a considerable portion of the field.

On the downthrown side of the fault, it is found that there is only a thin zone of distillate saturation in the 5,800-foot sand (listed as 6,400-foot on cross section *CC* (Fig. 11)), whereas on the upthrown side of the field approximately 26 feet of effective saturation was originally recorded. This difference in thickness of the zone of saturation and type of oil suggests that the original structure of the Saxet field below the Greta unconformity was almost entirely on what is now known as the upthrown side of the fault or at least occupied that area during the accumulation of oil in these lower beds.

Thus, it follows that the structure and accumulation of oil and gas on the downthrown side of the fault results directly from the action of faulting, because the beds were too low structurally to produce until after the faulting action took place causing reversal into the plane of the major fault. In the beds above the Greta unconformity, accumulation apparently partially pre-dated the final movement of the younger faults as is indicated by certain changes in water levels on both sides of the major fault. Actually, certain of the small faults on the downthrown side are determined, to a large extent, by change in water levels and producing conditions along certain lines.

An examination of cores of some of the sands in the Saxet field follows.

	Percentage Porosity		*Permeability, Millidarcys*	
Sand	*Range*	*Average*	*Range*	*Average*
4,400-foot	29–42	35	150–1,800	800
5,800-foot	7–45	31	0–6,100	2,400
6,300-foot	20–31	23	0–5,600	3,000
6,900-foot	21–34	28	0–2,500	1,300

Further examination of cores indicates that practically all of the sands in the Saxet field range from medium- to coarse-grained, firm, on the whole of fair to excellent porosity, and practically all have high permeability. These conditions under ordinary circumstances would make the Saxet field a highly advantageous one in which to drill, but unprofitable operation for some has resulted because of the faulted condition of the field or the thinness of the various zones of oil saturation.

In examining the cores from many of the sands which contain gas in the Catahoula and younger sand series, it is practically impossible to distinguish the gas odor but the sand ordinarily has a salty taste. It appears that only those sands which are capable of making some distillate on completion retain enough odor to be recognized from a field examination. These sands are found below the Greta unconformity. In many places, the top, or some portion of a sand body actually in the oil zone, becomes sufficiently shaly to appear to be a water or gas sand. Especially is this true when cores are examined at night. This type of report (encountering a water or gas sand in the middle or at the top of an oil sand) is a customary happening and closer inspection of the cores would tend to eliminate it. Commonly when such a core is recovered, drilling is resumed and the well is drilled on to the next sand. Development of this type has been common in the Saxet field and has resulted in dry holes which would have produced and many of which actually did produce later.

It is interesting to note that the portion of the section producing high-gravity (32°–50°) oils also produces all of the distillate, and that the section producing low-gravity (22°–29°) oils produces practically dry gas. Thus the high-gravity oil and distillate zone lies below the Greta unconformity and the low-gravity oil and dry gas zone lies above it.

DEVELOPMENT AND PRODUCTION

From the best of available sources as of March 1, 1940, the production of oil and gas in the Saxet field was as follows.

Gas was in excess of 201 billion cubic feet. Oil was in excess of 42 million barrels, divided as follows: high-gravity, 17,200,000 barrels (32°–57° A.P.I.) and low-gravity, 25,200,000 barrels (22°–29° A.P.I.).

A yearly production chart dividing the high- and low-gravity oil is not available until 1938 but a close estimate can be made of the division of production to that date from which time it is broken down. It is interesting to note that although the spectacular development of the Saxet field was in those sands producing high-gravity oil, more than half of the production has come from the low-gravity sands, which have at no time been spectacular.

During the month of March, 1940, 68 distillate wells produced 1,860 barrels per day. Separate figures on the production of distillate have been kept by the Railroad Commission only since January 1, 1939. During 1939, however, 908,011 barrels of distillate were produced. Distillate has been included with the high-gravity oil in the preceding table. On March 1, 1940, there were 492 producing oil wells in the Saxet field with a daily allowable by the Railroad Commission

of 15,463 barrels. This makes a total of 560 oil and distillate wells with a total daily allowed production of approximately 17,320 barrels.

In view of the fact that a great deal of unmetered gas is being used for gas-lift purposes, both in the Saxet field and in the Corpus Christi field, it is impossible to make an accurate statement as to the amount of gas being produced, but it is estimated to be approximately 155 million cubic feet per day. In all probability more than 300 billion cubic feet of gas have been produced during the life of the field. At present there are 44 wells producing dry gas in addition to the 68 which produce gas and distillate.

TABLE II

OIL PRODUCTION IN BARRELS, SAXET FIELD, NUECES COUNTY, TEXAS, APRIL 1, 1940

Year	*Low-Gravity*	*High-Gravity*	*Total*
1930	17,967		17,967
1931	152,288		152,288
1932	469,270		469,270
1933	861,039		861,039
1934	737,766		737,766
1935*	1,226,419		1,226,419
1936			4,804,836**
1937			12,969,259**
1938	6,098,248	5,887,129	11,985,377
1939	3,712,559	4,480,027	8,192,586
1940***	503,538	503,360	1,009,898
	25,197,009	17,229,133	42,426,142

* High-gravity oil produced during and prior to 1935 is negligible.
** High- and low-gravity oils undifferentiated for these two years except by study of depths from which production came, resulting in division figure accumulated through 1937 of 7,355,617 barrels high-gravity oil and 13,882,664 barrels of low-gravity oil.
*** Includes only production for months of January and February.

On March 1, 1940, there were, in the flowing-well column, 153 high-gravity oil and distillate wells and 120 low-gravity oil wells, while in the agitated column (pumping and gas lift) there were 54 high-gravity oil wells and 233 low-gravity oil wells. Thus of the 560 producing wells in the field, only 273 of them flow naturally.

There are 54 operating companies in the Saxet field at present and production practices are as varied as the number of companies. In the earlier history of the field, it was customary to core through the gas zone of a sand and on into the oil saturation and set casing well up into the gas zones. This type of operation resulted in gas wells which sprayed a little oil and as such were not profitable. Gradually more and more of the zone of gas saturation was cased off. It was in the Gulf Coast's Maggie Harrell No. 1, completed in the 4,500-foot sand with a high gas-oil ratio, that the first bottom-hole choke was employed in the field[13] when the operators pulled the tubing and placed

[13] J. J. St. John, personal communication.

a $\frac{3}{8}$-inch positive choke in the bottom of the tubing and recompleted the well.

With the discovery of the 5,800-foot sand, the practice of completion through casing perforations became predominant in the field. This type of completion made the determination of gas-oil and oil-water contacts exceedingly difficult because of the question of whether or not good cement jobs were had. Completion by perforation, however, pre-dated the invention of the gun-perforating method as far as the Saxet field was concerned since some of the earlier wells were perforated by mechanical methods. The development of Schlumberger side-hole coring has led many operators to drill their wells to the desired total depth, survey the hole with an electrical logging device, take side-hole cores, set pipe if justified, and complete by perforation.

In some parts of the field, operators considered it profitable not only to twin locations but in one case to drill as many as four wells on the same location. Although, as previously stated in this paper, there are 30 known separate oil- and distillate-producing zones, there is no one location where all of them would produce. In the one case where four wells were drilled on the same location, that is, approximately 50 feet apart, only four possible known producing zones existed.

Although the spacing pattern for the field is 10 acres to the well, due to the many sands present, the effective spacing pattern is vastly wider when calculated on the basis of individual sands. This statement does not hold true for the 5,800-foot sand which was developed completely and which at the present time is in the last stages of its productive history. During the past year (1939) wells were recompleted in the 5,800-foot sand above what originally was proved to be the gas-oil contact by drill-stem tests. This means that the original gas cap has been dissipated and that the active water drive present in the sand has flushed the oil up into that portion of the sand originally occupied by the gas cap, thereby leaving in the sand a considerable part of the oil which might have been produced under more favorable practices of operation.

Many of the wells have been recompleted in shallower or deeper sands by plugging back or deepening wells which have ceased to produce from the original sands. The present distillate production results in the main from these recompletions. At present there are several work-over rigs active in the field.

On March 10, 1937, the Southern Minerals completed its Saxet absorption gasoline plant which to April 1, 1940, had recovered approximately 30,200,000 gallons of gasoline from approximately 52,600

million cubic feet of gas. The gas used was that produced along with the production of oil.

In June, 1939, the Colombian Carbon Company's Saxet carbon-black plant began operations using residue gas from Southern Minerals' gasoline plant. The carbon-black unit is to date the only one on or near tidewater, uses 26 million cubic feet of gas and produces approximately 36,000 pounds of carbon black daily.

The Republic Natural Gas Company furnishes the City of Corpus Christi with gas and also furnishes gas to the United Gas System's pipe line.

TABLE III

SUMMARY DATA, SAXET FIELD, NUECES COUNTY, TEXAS, APRIL 1, 1940

1. Producing area	9,100 acres
2. Production	
A. Gas (not including waste and that used for gas lift, *et cetera*	201 billion cubic feet
B. Oil; high-gravity and distillate (32°–57° gravity)	17,229,133 barrels
C. Oil; low-gravity (22°–29° gravity)	25,197,009 barrels
D. Oil; total both high and low gravities	42,426,142 barrels
E. Distillate production for year 1939 (included in high-gravity oil figure)	908,011 barrels
3. Well data	
A. Total wells drilled	893
B. Total producing oil and distillate	560
C. Total producing high-gravity oil	139
D. Total producing low-gravity oil	353
E. Total producing distillate	68
F. Total wells flowing naturally	273
G. Total wells on artificial lift	287
4. Daily production	
A. Oil and distillate total	17,320 barrels
(1) Distillate	1,860 barrels
(2) High-gravity	8,707 barrels
(3) Low-gravity	6,756 barrels
B. Gas (estimated)	155 million cubic feet
C. Total wells producing dry gas	44
5. Gas pipe lines serving field	
A. Republic Natural Gas Company	
B. Southern Pipe Line Corporation	
C. Southern Coast Corporation	
D. Richardson Gas System	
E. Renwar Gas System	
6. Gasoline plants daily capacity	55 million cubic feet
Southern Minerals (absorption type)	
7. Oil pipe lines serving field	
A. Southern Pipe Line Corporation	
B. Republic Pipe Line Corporation	
C. Texas Pipe Line Company	
D. M-A-R Pipe Line Company	
E. Amsco Pipe Line Company	
F. Crown Central Transportation Corporation	
G. Humble Pipe Line Company	
H. Houston Pipe Line Company (gathering system for Houston's refinery at Viola)	
8. Refineries	
The Houston Oil Company	
(Refineries at Corpus Christi omitted)	

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GEOLOGICAL NOTES

ROGERS POOL, MONTAGUE COUNTY, TEXAS[1]

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The Rogers pool is in north-central Montague County, Texas, and adjoins the west limits of the townsite of Nocona. The discovery well, the Rogers and Rogers' Burnett No. 1, near the center of the pool, is 1,678 feet from the north line and 1,012 feet from the east line of the J. Lenow Survey A-433.

The presence of an anticlinal structure in this area has been known for a number of years. As early as 1923 H. B. Fuqua worked the surface and defined an east-west elongate anticline having approximately 60 feet of closure. Immediately following the work by Fuqua the Gulf Production Company drilled three tests on the Benton farms in an area 1 mile east of Nocona. The tests were abandoned in Strawn at depths above the sands which have recently been proved to be productive. In 1937 the Stanolind Oil and Gas Company mapped the area by means of seismograph in order to detail the structure indicated from the wells drilled.

The structure, as now indicated by subsurface mapping on markers of Strawn and pre-Strawn age, is a westward-plunging asymetrical anticline composed of two closed features. The entire structure is 4 miles long and 1 mile wide with a minimum of 200 feet of closure, the highest known point being 1 mile east of Nocona.

In October, 1938, Youngblood and Foree *et al.* spudded the discovery test and drilled to a depth of 4,139 feet. In December, 1938, the well and leases were taken over by Rogers and Rogers of Oklahoma City, Oklahoma. The new owners completed the test, January 18, 1939. The initial production was 189 barrels of 44° gravity oil flowing through a 9/16-inch choke in 7 hours, from a medium-grained sandstone of the Strawn group encountered from 4,645 to 4,656 feet.

The second producing zone in the field was discovered in September, 1939, by the Rogers and Rogers' Burnett No. 2, 257 feet from the east and 2,000 feet from the north of the J. Lenow Survey. The initial production of this test was 316 barrels of 44° gravity oil in 3 hours from a Strawn sandstone from 4,278 to 4,304 feet.

[1] Manuscript received, August 14, 1940.

[2] Geologist, Stanolind Oil and Gas Company.

The third producing zone was discovered in December, 1939, by the Stanolind Oil and Gas Company's Davis No. 2, 467 feet from the south line and 1,074 feet from the east line of the W. J. Wells Survey. This test failed to encounter favorable showings of oil in either the 4,300- or the 4,600-foot sandstone and was drilled to the total depth of 5,249 feet where it was completed, having an initial production of 80 barrels in one hour from a conglomerate in the Nocona limestone (probably Bend) section from 5,228 to 5,233 feet.

The consensus is that the "Nocona" limestone is Bend in age. This opinion is based on the lithologic similarity of the dark limestone and associated black shales of the "Nocona" section to the Bend limestone and black shales of North Texas. The conglomerates in the Nocona limestone section are composed chiefly of worn quartz grains ranging in size from ½ millimeter to 1 inch in diameter, the average grain size being 2 millimeters. These conglomerates range in thickness from 1 to 15 feet and are found to be widespread as a zone, but are extremely variable in porosity and thickness of individual beds. Similar conglomerate deposits are found in the Bend group in north-central Young County, northern Comanche County, and other counties along the crest of the Bend arch. As more paleontological evidence is brought to light it will be possible to determine definitely the age of the Nocona formation.

On June 30, 1940, 23 producing wells had been completed in the Rogers pool; 9 wells were producing from the 4,300-foot zone, one from the 4,500-foot zone, 4 from the 4,600-foot zone, and 9 from conglomerates in the Nocona limestone zone. Five wells were being drilled within the limits of the pool and one, the Sinclair Prairie's Benton No. 1, 3,800 feet from the north line and 330 feet from the west line of the T. R. Jackson Survey and 8,000 feet east of the limits of the Rogers pool, was on a separate part of the structure, 175 feet higher on the Nocona limestone than the producing area west of the townsite.

In close proximity to the Rogers pool 5 dry holes had been drilled to the Ellenburger dolomite series during 1939 and the first 6 months of 1940. The proved producing area was 1 mile wide by 2 miles long. A much larger area will probably be proved by additional drilling.

A type columnar section for the pool is as follows.

Depth in Feet	
0–1,700	Cisco, upper Pennsylvanian
3,000	Canyon, middle Pennsylvanian
5,150	Strawn, middle Pennsylvanian
5,350	Bend, lower Pennsylvanian
?	Ellenburger, Lower Ordovician

The section encountered by the Ramsey Oil Company's Loring No. 1, J. Lenow Survey, a dry hole 2,500 feet south of the Sunray's Burnett No. 2, a producing well in the south edge of the pool, is as follows.

Depth in Feet	
0–1,800	Cisco, upper Pennsylvanian
3,000	Canyon, middle Pennsylvanian
5,700	Strawn, middle Pennsylvanian
6,220	Bend, lower Pennsylvanian
6,370	Mississippian (questionable)
6,530	Viola, Upper Ordovician
6,940	Simpson, Middle Ordovician
6,988 total depth	Ellenburger, Lower Ordovician

The data obtained from the drilling of the Ramsey Oil Company's Loring No. 1 shows that the Upper Ordovician beds penetrated by this test are not present in the producing area, thus defining a minimum 1,593 feet of south dip (or displacement) on the Lower Ordovician beds, and a minimum of 873 feet of dip on the base of the Pennsylvanian deposits.

BONITA DISCOVERY, MONTAGUE COUNTY, TEXAS[1]

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Ardmore, Oklahoma

The Bonita field lies near the village of Bonita, in east-central Montague County, Texas, 8 miles southeast of the town of Nocona. The Sinclair Prairie Oil Company's A. P. Howard No. 1, discovery well, is 1,480 feet from the south line and 420 feet from the east line of the Howard lease in the William Wallace Survey, Abst. 841, and the J. C. Howard Survey, Abst. 1299. This well was commenced on January 1, 1940, and completed on February 11, 1940, at the total depth of 5,249 feet. Seven-inch casing was cemented at 5,241 feet; the well was bailed in and produced 265 barrels of oil in 3 hours through 2-inch open tubing with a gas volume of approximately 1,250,000 cubic feet. The oil has a dark green color and an average gravity of 40°. It comes from a basal Strawn, very coarse, conglomeratic quartz sand found at 5,239–5,249 feet.

The typical section of the field is as follows.

Depth in Feet		
0– 300	Cretaceous	Trinity sand
1,200	Permian-Pennsylvanian	
3,240	(?)Pennsylvanian	Canyon group[3]
5,800	Pennsylvanian	Strawn group
?	Ordovician	Ellenburger group

[1] Manuscript received, August 26, 1940.

[2] District geologist, Sinclair Prairie Oil Company.

[3] M. G. Cheney, "Geology of North-Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), pp. 65–118.

Two offsets to the discovery well failed to produce in the 5,200-foot sand and were drilled to the Ellenburger limestone. Numerous coarse quartz and arkose sands with showings of oil and gas were drilled in these wells, which were later plugged back and completed from a 5,400-foot arkosic sand, the principal producing bed in the field. The Ellenburger limestone had showings of oil in both wells, but produced salt water in the Howard well, the south offset to the discovery well, and the higher of the two deep tests.

Several differences of opinion have been expressed concerning the age of the section which contains the producing zones in this field. On paleontological evidence we find that the beds from approximately 5,200 feet to the Ellenburger are more closely allied to the Pennsylvanian in the Ardmore basin, namely, part of the Dornick Hills formation in the Des Moines series. This reason alone seems to identify the beds as basal Strawn.

The structure, mapped by seismograph work done by the Sinclair Prairie Oil Company during the summer of 1939, is a domal anticline elongate northwest and southeast. While closure in the basal Strawn is probably responsible for the accumulation of oil, there is some suggestion that production will be obtained from both lenticular and continuous sands.

At present the field consists of two producing wells from the 5,200-foot sand, five producing wells from the 5,400-foot sand, and seven drilling wells.

ASPERMONT POOL DISCOVERY, STONEWALL COUNTY, TEXAS[1]

FRED M. HAASE[2]
Abilene, Texas

The Shell Oil Company's Smith No. 1, discovery well of the Aspermont pool, is located 330 feet from the west line and 2,310 feet from the south line of Sec. 143, Block 1, H. & T. C. Survey, in southeastern Stonewall County, Texas.

The structure, on which the well was drilled, was found by surface mapping and later checked by shallow core-drilling.

Smith No. 1 was drilled with cable tools, and was completed on August 9, 1940, the gauge by the Railroad Commission of Texas being 581 barrels of oil and 618,000 cubic feet of gas through open 2-inch tubing in 24 hours. The gravity of the oil tested 38.2° at 74° F.

[1] Manuscript received, September 20, 1940.

[2] Shell Oil Company, Inc.

The "pay" consists of soft streaks in cream-colored, crystalline, crinoidal limestone, encountered at 6,005 feet and penetrated to 6,065 feet, the total depth. According to its lithologic character, this limestone is designated as Mississippian, but in contrast with Mississippian limestone in other deep tests in the area, the Mississippian limestone in Smith No. 1, as far as penetrated, does not contain any chert.

Smith No. 1 establishes a new record for depth of production in this area and is one of the few wells producing from the Mississippian in the state.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 10 (OCTOBER, 1940), PP. 1841–1846

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available, on loan, to members and associates.

STRATIGRAPHY OF THE EASTERNMOST VENTURA BASIN, CALIFORNIA, BY RICHARD H. JAHNS

REVIEW BY WILLIAM S. W. KEW[1]
Los Angeles, California

"Stratigraphy of the Easternmost Ventura Basin, California, with a Description of a New Lower Miocene Mammalian Fauna from the Tick Canyon Formation," by Richard H. Jahns. *Carnegie Institution of Washington Pub. 514, Contributions to Paleontology Paper IX* (June 27, 1940), pp. 145–94.

This paper is a welcome clarification of a problem which concerns geologists and paleontologists who deal with both invertebrate and vertebrate fossils. For some time a discussion has been in progress between two schools of thought in California relative to the age of the 4,000-foot-thick Mint Canyon formation. The chief disagreement between paleontologists regarding the age of the Mint Canyon formation exists in the views with reference to the genus *Hipparion*. By some, this genus is considered to range downward in geologic time no farther than the base of the Pliocene, according to European standards. As Jahns points out, however, the evidence for its pre-Pliocene appearance in the Mint Canyon is proved by the stratigraphic position of the formation, since it lies unconformably below marine beds containing an upper Miocene invertebrate fauna. The paper brings to notice the thoughts of a number of geologists who have had years of experience in Ventura Basin, that the Mint Canyon represents essentially the non-marine equivalent of the marine Modelo formation as defined by Hudson and Craig, and possibly the lower part of the Neroly formation. The type section of the Modelo formation is in the central part of the Ventura Basin, the original definition of which included beds now referred to the Neroly formation, the latter overlying the Mint Canyon strata.

Jahns has also described the unconformably underlying Tick Canyon formation. The recognition of this new formation explains the presence of a vertebrate fauna which had for many years been recognized as being older than that from the Mint Canyon. The oldest sedimentary formation in the area, named the Vasquez, has also been identified as to age much more closely. The work by Jahns is well worth reading by all geologists and paleontologists, as it is one of the relatively few paleontologic theses that presents such detailed geology on all the sedimentary rocks, the Mint Canyon formation being divided into 27 parts which have been delineated on the accompanying map. Such work adds materially to the validity and impressiveness of his faunal correlations.

Although the paper is not one directly applicable to petroleum geology, nevertheless it is indirectly of interest since the Modelo formation, the marine counterpart of the Mint Canyon formation, is one of the main oil-bearing

[1] Standard Oil Company of California. Manuscript received, August 22, 1940.

series of California. It is of considerable importance to know the exact geologic age of these characteristic strata where found in wells, since the deposits are not uncommonly penetrated in those drilled in the upper part of the Ventura Basin.

PETROLEUM DEVELOPMENT AND TECHNOLOGY, 1940, BY THE A. I. M. E. PETROLEUM DIVISION

REVIEW BY PAUL D. TORREY[1]
Houston, Texas

"Petroleum Development and Technology, 1940," by the Petroleum Division. *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 136 (1940). 597 pp. Price, $5.00.

The annual volume of the Petroleum Division includes papers and discussions presented at meetings held at Galveston, Texas, October 5–7, 1939; in Los Angeles, California, October 19–20, 1939; and in New York, New York, February 12–15, 1940. Reference is made to certain papers presented at these meetings that are not contained in the volume, but which have been published in *Petroleum Technology* and in various trade journals. The volume contains five chapters, the titles of which are: Production Engineering, Engineering Research, Economics, Production, and Refining.

Chapter I, Production Engineering, is made up of five separate papers. "A Resumé of the Application of Gravel Packing to Oil Wells in California" describes a relatively new method employed in the completion of oil wells which has made possible more consistent rates of production and has eliminated much of the trouble encountered from sanding-up of wells and abrasion of pumping equipment. It is notable that this method is now being used in other fields outside of California with very satisfactory results, and that pregravel packed liners have been set effectively. The paper on "Multistage Stabilization of Crude" describes methods employed in the Haft Kel field located in southwest Iran for the recovery and preservation of light gasoline hydrocarbons. Crude stabilization, using a very similar procedure, has been used in the United States in connection with pressure-maintenance operations. The process provides for the efficient recovery of certain hydrocarbon fractions which otherwise might be partially lost and their admixture with crude oil. The lighter fractions may therefore be readily transported with little loss where other means of movement are not available, and at the same time the gravity of the crude is increased. The paper, "Principles of Well Spacing," contains valuable formulae for the proper development of oil reservoirs which should find particular application in programs of unitization as well as in the ordinary development of oil fields. In the paper, "Radial Filtration of Drilling Muds," the loss of water into permeable zones and the formation of filter cake from mud is discussed on the basis of laboratory investigations and theoretical calculations. Suggestions are made as to how optimum filtration properties of mud can be obtained. An accurate method for the location of the position of cement behind casing is described in the paper on "Detection of Radioactive Cement in Cased Wells." All of the papers in this chapter clearly point the way to methods designed for the more efficient development and recovery of petroleum.

[1] The Sloan and Zook Company. Manuscript received, August 26, 1940.

Chapter II, Production Research, contains nine papers. The papers, "Visual Studies of the Flow of Air-water Mixtures in Vertical Pipe" and "Flow of Gas-liquid Mixtures through Consolidated Sand," present valuable experimental information regarding the movement of fluids through reservoir rocks and, after entering the well, up through the well bore. Four papers in this chapter are devoted to the behavior of the lighter hydrocarbons and hydrocarbon mixtures. These data should find very practical application in the operation of recycling and natural gasoline recovery plants. The last three papers of the chapter are devoted to theoretical and experimental considerations of the properties and treatment of materials making up rotary drilling mud. Most of the papers in this chapter emphasize the analysis of various production problems by petroleum physics and physical chemistry.

Chapter III, Petroleum Economics, contains four outstanding and thought-provoking papers devoted to studies of excessive drilling, the desirability of various types of crude from a refining standpoint, the factors affecting the demand for motor fuel, and the consumption of petroleum products. The subjects considered have an important bearing on the rate of exploration for and development of oil fields and thus are of vital interest to petroleum geologists.

Chapter IV, Production, contains thirty-two papers on domestic areas and 15 papers on foreign countries. These papers describe significant developments in the subject areas and countries as well as giving much valuable and up-to-date statistical information regarding individual fields. Many of the papers were written by members of the A. A. P. G., and thus include discussions of trends of exploration and much pertinent geological information regarding new discoveries. Of general interest can be cited the rapid depletion of the Oriskany sand gas fields in the eastern states; the further development of flush production in the Music Mountain field in northern Pennsylvania; the continued increase in development and production in Illinois, and adjacent parts of Indiana and Kentucky; the great attention that is being evidenced in secondary recovery projects in Kansas and Oklahoma; the discovery of commercial oil production in Mississippi; the orderly and scientific development of the deep fields of Arkansas; the installation of numerous recycling and pressure-maintenance plants in Louisiana and Texas; and the discovery of relatively few new fields in the Rocky Mountain states and in California. Accurate data on recent developments and production in European fields are not available owing to war conditions, although it is suggested that strenuous efforts are being made to build up production to a maximum level. No important new discoveries appear to have been made in Asia Minor, Iran, India and Burma, or the Dutch East Indies. Mexican development and production have suffered seriously under government control of the oil industry. Notable gains in production have been attained in several South American countries.

Chapter V, Refining, consists of one paper on "Review of Refinery Engineering for 1939." Advanced methods in refining such as catalytic reforming, polymerization, alkylation, and desulphurization are discussed. The use of petroleum products for the manufacture of ethyl chloride—a base compound for the manufacture of tetraethyl lead—ethylene glycol, and synthetic rubber is noted. An increased demand for better grades of motor fuel has necessitated the reconstruction of several large refining units.

"Petroleum Development and Technology, 1940" continues a trend es-

tablished several years ago wherein the Petroleum Division of the A. I. M. E. is concentrating its attention on problems of research, economics, and statistical reviews. This has eliminated to a very great extent some conflict which had existed previously with other organizations associated with the oil industry with reference to production practice and technology, and refining. From the standpoint of reference value alone, the volume should be most welcome in the library of every geologist. The general quality of the papers is excellent, and they reflect clearly the care that has been exercised in the selection of authors and the care and attention which have been devoted to the preparation of the papers.

RECENT PUBLICATIONS

ARKANSAS

"Lower Cretaceous and Jurassic Formations of Southern Arkansas, and Their Oil and Gas Possibilities," by Ralph W. Imlay. *Arkansas Geol. Survey Inform. Cir. 12* (Little Rock, 1940). 64 pp., 17 tables, 26 pls. Paper. 8.5×11 inches. Price, $1.25+$0.15 postage.

CALIFORNIA

*"Type Locality of the Cretaceous Chico Formation," by J. A. Taff, G. D. Hanna, and C. M. Cross. *Bull. Geol. Soc. America*, Vol. 51, No. 9 (September 1, 1940), pp. 1311–28; 2 pls., 1 fig.

*"Gravity Section across the Sierra Nevada," by W. D. Johnston, Jr. *Ibid.*, pp. 1391–96; 2 figs.

*"Some Features of the Faulting in Southern California," by William J. Miller. *Jour. Geol.*, Vol. 48, No. 4 (Chicago, May-June, 1940), pp. 385–420; 1 fig.

*"Metamorphism of Sediments of the Deep Well near Wasco, California, and of the deeply Buried Eocene Sediments near Ventura, California," by John B. Lyons. *Ibid.*, pp. 436–43; 1 fig.

**California Oil World 1940 Reference Edition*. 172 pp. many illus., 27 large maps. This enlarged and improved successor to the *California Oil World Directory* of 1939 contains these five principal sections: (1) Textbook on Safety, pp. 10–70; (2) California Oil Operators, pp. 71–146; (3) Statistical Section, pp. 147–59; (4) California Oil Field Section, pp. 160–70; and (5) Map Section, pp. 171–74 with 14 folded map inserts. The illustrated safety manual, prepared from the records of the California Petroleum Safety Board, was written for the foremen of the oil industry and contains chapters for the drilling, producing, pipeline, and refining divisions, besides general first-aid instructions. The directory lists 2,693 companies and individual operators with statistics. Fifty-two of California's oil fields, besides being described statistically by production tables, are represented by large clear maps showing locations of wells and properties and most of them are structure-contoured on the tops of the oil zones. This useful directory of the California oil industry, cloth-bound, 9.25×12.25 inches outside dimensions, is sold by Petroleum Publishers, Inc., Petroleum Building, Los Angeles, at $5.00 per copy.

CANADA

*"Chemical Treatment of Ontario Oil Wells," by P. E. Fitzgerald and E. G. Hardy. *Canadian Oil and Gas*, Vol. 1, No. 2 (Toronto, August, 1940), pp. 10–12 and 30; illus.

*"Drilling Conditions in Turner Valley," by Vernon Taylor. *Ibid.*, pp. 14–15 and 16–20; illus.

GENERAL

"Correlation Index to Aid in Interpreting Crude-Oil Analyses," by Harold M. Smith. *U. S. Bur. Mines Tech. Paper 610* (1940). 4 pp. For sale by Supt. of Documents, Washington, D. C. Price, $0.10.

*"Time and Stratigraphic Terminology," by A. H. Sutton. *Bull. Geol. Soc. America*, Vol. 51, No. 9 (September 1, 1940), pp. 1397–1412.

*"Taphonomy: New Branch of Paleontology," by J. A. Efremov. *Pan-Amer. Geol.*, Vol. 74, No. 2 (Des Moines, Iowa, September 1, 1940), pp. 81–93.

GREAT BRITAIN

*"The Structure of Gower," by T. Neville George. *Quar. Jour. Geol. Soc. London*, Vol. 96, Pt. 2 (July 25, 1940), pp. 131–98; 2 pls., 14 figs. Upper Paleozoic geology along the southern borders of Wales.

ILLINOIS

*"Solution Cavities in the Joliet Limestone of Northeastern Illinois," by J Harlen Bretz. *Jour. Geol.*, Vol. 48, No. 4 (Chicago, May-June, 1940), pp. 337–84; 33 figs.

INDIA

*"The Upper Khirthar Beds of North-West India," by Lewis Merson Davies. *Quar. Jour. Geol. Soc. London*, Vol. 96, Pt. 2 (July 25, 1940), pp. 199–230; 4 pls. Description of "the principal contents of the latest Eocene beds at Spintangi, with the object of showing what Khirthar fauna, if any, can be said to succeed Nuttall's 'Middle Khirthar.'"

LOUISIANA

*"South Louisiana Continues Advance in Oil Production," by Donald J. Goodwill, Jr., *Louisiana Conservation Rev.* (Civil Courts Building, New Orleans, Spring, 1940), pp. 8–10; 4 charts.

*"Ground Water in Grant and La Salle Parishes, Louisiana," by J. C. Maher. *Ibid.*, pp. 36–41; 5 figs.

NEW MEXICO

*"Outlines of New Mexico Geology," by Charles Keyes. *Pan-Amer. Geol.*, Vol. 74, No. 2 (Des Moines, Iowa, September, 1940), pp. 103–42; 3 figs., 10 pls., 2 charts. First article of a series.

OKLAHOMA

*"New Pools May Be Discovered in Osage Indian Reservation, Oklahoma." *U. S. Dept. Interior Inform. Service P. N. 112618* (August 29, 1940). One-page advance notice of a preliminary map of the Burbank and South Burbank oil fields prepared by N. W. Bass. A few copies of the map with a brief discussion are available on application to the director, U. S. Geological Survey, Washington, D. C. Free.

WEST VIRGINIA

*"Characteristics of Minable Coals of West Virginia," by A. J. Headlee and John P. Nolting, Jr. *West Virginia Geol. Survey*, Vol. 13 (1940). 272 pp., 18 pls., 112 figs. Cloth.

WYOMING

*"Structure Contour Map of the Byron Anticline, Wyoming." *U. S. Dept. Interior Inform. Service P. N. 111911* (August 28, 1940). One-page advance notice of map showing contours on the Embar formation, prepared primarily for official use of the Geological Survey. Available for public inspection at the U. S. Geological Survey, Washington, D. C., and at Casper and Thermopolis, Wyoming.

*"Geologic Map and Sections of the Northern Part of the Baxter Basin Gas Field, Sweetwater County, Wyoming." *Ibid., P. N. 112797* (September 3, 1940). Two-page advance notice of a map showing areal and structural geology, prepared by W. B. Kramer and G. G. Frazier, assisted by Robert McMillan and J. G. Cox under the supervision of C. E. Dobbin. A few copies available for free distribution at the offices of the U. S. Geological Survey, Washington, D. C.; U. S. Customhouse, Denver, Colorado; and Federal Building, Casper, Wyoming.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Okla.), Vol. 14, No. 5 (September, 1940).

"Upper Jurassic Pelecypods from Mexico," by Ralph W. Imlay.

"New Larger Foraminifera from the Claiborne of Mississippi," by Donald W. Gravell and Marcus A. Hanna.

"Conodonts from the Devonian and Associated Clays of Minnesota," by Clinton R. Stauffer.

"The Apical End of *Actinoceras*," by Rousseau H. Flower.

"Some Devonian Actinoceroidea," by Rousseau H. Flower.

"*Blastocerina*, New Name for *Blastoceras* Flower and Caster," by Rosseau H. Flower.

"Avian Remains from the Pleistocene of Central Java," by Alexander Wetmore.

"Holotype of *Plesiosaurus longirostris* Blake and Classification of the Plesiosaurs," by Theodore E. White.

"Ceratopsidae from Alberta," by C. M. Sternberg.

"*Thescelosaurus edmontonensis*, N.Sp., and Classification of the Hypsilophodontidae," by C. M. Sternberg.

"Cranial Foramina of North American Beavers," by Everett Clair Olson.

"*Sphaerospongia* in the Tully Formation," by John W. Wells.

"Two New Cypraeas from Costa Rica," by William M. Ingram.

"Supplementary Notes on the Occurrence of Tertiary Noetinae," by F. Stearns MacNeil.

"Pliocene Mollusks from a Well at Sanford, Florida," by Sidney A. Stubbs.

"Corrections to the Basal Bonneterre Fauna," by Christina Lochman.

"*Alsataspis bakeri*, A New Lower Ordovician Trilobite," by F. E. Turner.

"*Cantharus bentsonae*, New Name for *C. cowlitzensis* Turner," by F. E. Turner.

"A Pleistocene Occurrence of *Libinia dubia*, a Brachyuran," by William H. Easton.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 10 (OCTOBER, 1940), PP. 1847-1850

THE ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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Mark Eugene Stump, Tulsa, Okla.
Hubert E. Bale, Leslie A. Johnston, Harry F. Wright

Olai Ingolf Torkelsen, Hynes, Calif.
E. K. Soper, Wayne M. Smith, U. S. Grant

Paul H. Umbach, Magnolia, Ark.
John Doering, William D. Neiler, Philip M. Konkel

Russell Benson Wheeler, Bogota, Colombia, S. A.
Wayne M. Smith, U. S. Grant, Frank B. Notestein

Albert Fletcher Woodward, Laguna Beach, Calif.
E. W. Galliher, Harry P. Stolz, E. R. Stanley

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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Memorial

EDWIN BUTCHER HOPKINS
(1882–1940)

Edwin Butcher Hopkins died in Baylor Hospital, Dallas, Texas, on the afternoon of July 5, 1940, following a paralytic stroke which occurred on the morning of the same day.

Hopkins, a pioneer petroleum geologist and independent oil producer, was born in Evans, West Virginia, October 25, 1882, the son of Andrew Delmar Hopkins, the eminent bioclimatist who was for many years the senior entomologist of the United States Department of Agriculture, and Delia Butcher Hopkins.

He married Amy Longcope, daughter of a pioneer Houston family, in Houston, Texas, June 20, 1913, and is survived by his widow, his daughters, Mrs. Ted Fitch, Mrs. Jack Munger, and the Misses Louise and Madeleine Hopkins, and by his son, Edwin Butcher Hopkins, Jr.

Hopkins was a student at the University of West Virginia, 1899–1902; George Washington University, 1903–1904; and attended geological lectures at Cornell University, 1905–1906.

During the summers of 1903–1904, he worked on topographic surveys by the United States and West Virginia Geological Surveys; was assistant to the State geologist of Louisiana, 1905–1906; and had charge of drilling for the New York Commission on Additional Water Supply, Gas, and Electricity during 1906.

He was a member of a United States Geological Survey party doing geological work in southwestern Wyoming during the field season of 1907. This party, one of several under the general supervision of Arthur C. Veatch, started under the immediate direction of George C. Matson, who retired because of illness, and was replaced by E. Eggleston Smith. W. B. Heroy was a member of this party.

The field season of 1908 was spent in northeastern Montana and North Dakota as a geological assistant to Carl D. Smith. The writer was also an assistant in this party and to this circumstance he owes the beginning of a lifelong and intimate friendship with Hopkins.

In April, 1909, Hopkins became an assistant classifier on the newly organized Land Classification Board of the United States Geological Survey, a position which he resigned in July, 1909, to go to Mexico as a field geologist for the Mexican Eagle Oil Company, Ltd., a Pearson enterprise but recently organized.

C. Willard Hayes, then chief geologist of the United States Geological Survey, early in 1909, in company with David T. Day, had made a hurried official or semi-official visit of inspection to the Mexican oil fields. While there, he had met Sir Weetman Pearson, who later became the first Viscount Cowdray. Pearson, head of the great English contracting firm of S. Pearson and Son, had plunged heavily into the oil business in Mexico in 1901, inspired by the startling success of Captain Anthony F. Lucas at Spindletop. Thousands of acres of land had been bought and leased, oil had been discovered, pipe

lines and refineries had been built, and a violent war for markets was being fought with the old Waters Pierce Corporation, which then held almost a complete monopoly of the Mexican trade. In the face of rapidly mounting investment, attempts to develop production had been consistently discouraging.

EDWIN BUTCHER HOPKINS

Much geological work had been done under the general direction of Sir Boverton Redwood by the elder and younger Daltons, by P. C. A. Stewart, Grimley, Moon, Madgwick, G. Jeffreys, and F. Laurie, but such fields as had been discovered were of low caliber and short-lived. Sir Weetman engaged Dr. Hayes to take charge of the company's geological work in a consulting capacity and to furnish a staff for the work. Hopkins was the first geologist sent to Mexico under this arrangement, followed shortly by Chester W.

Washburne and by the writer. Frank R. Clark was similarly employed in 1910. Hayes resigned as chief geologist of the Survey in 1911 and went to Mexico as vice-president and general manager in charge of exploration and production for the Mexican Eagle Oil Company, Ltd.

Hopkins had become an assistant to the general manager by 1912 and, 1913–1914, was manager for an allied enterprise, the Cuban Oil Company, which was engaged in prospecting for oil in the Island of Cuba.

Resigning from the Pearson enterprises in 1914, he became manager in Tampico for the International Petroleum Company and allied interests controlled by John Hayes Hammond and the corporate ancestors of the present Seaboard Oil Company.

In 1916, he resigned from this position and returned to the United States where he opened offices as consulting petroleum geologist and engineer, first in Washington, then Houston, New York, and Dallas.

Hopkins was one of the pioneer oil geologists who early became interested in production and production problems. His viewpoint was intensely practical and theoretical problems interested him but little. He was successful as a geologist, locating the discovery wells for the Tanhuijo field, Mexico, and for the Rattlesnake field, San Juan basin, New Mexico. From 1912 on, he was interested almost altogether in management, in production problems, and in finance. He acted as agent in the United States for the Cia. Venezolana de Petroleo, S. A., a company controlled by the late President Gomez, during the late twenties; was a director of the Santa Fe Corporation; was one of the founders and a director of Petroleum Finance Corporation; and a founder, director, and vice-president of Drilling and Exploration Corporation. At the time of his death, in addition to many enterprises in which he was substantially interested, he was vice-president and manager of the American Maracaibo Company.

Hopkins was a member of the governing boards of the Dallas Museum of Fine Arts, of the Dallas Symphony Society, of the Texas Country Day School, and a trustee of the Dallas Public Library. He was a member of the Siwanoy, Houston, Caracas, Dallas, and Brook Hollow Country Clubs and of the Engineers Club, New York, the Houston Club, and the Dallas Petroleum Club.

He was a charter member of the Society of Economic Geologists, member since 1918 and vice-president in 1937 of the American Association of Petroleum Geologists, a member of the American Institute of Mining and Metallurgical Engineers, a member of the American Petroleum Institute, and a member and director of the Independent Petroleum Association of America.

Hopkins was a born pioneer; first, in his own profession and, afterwards, in Mexico and Venezuela and was widely known in the petroleum industry and in financial circles. To know him was to like him and to know him, even for a short time, was to be his friend. He was a charming and delightful person, possessed of a surpassing genius for friendship.

Many of us can say, as one of his friends wrote, "He was one of my life's best friends."

E. DEGOLYER

DALLAS, TEXAS
September 10, 1940

GUSTAVUS EDWIN ANDERSON
(1879–1940)

Professor G. E. Anderson, who died suddenly of heart attack on the evening of August 31, 1940, had not been in good health for several years. Still he carried a full schedule of University work, continued preparation of his book on sedimentation, and taught during the recent summer session.

He was born at Berbik, Sweden, July 11, 1879. At the age of twelve, he came with an older brother to Quebec and thence to New York City, where he arrived with a capital of ten cents. He soon went to Pleasant Grove, Utah, where he worked very hard on a farm for three years. Then at Mercur, Utah, he worked in the mines until he was nineteen, while he was continuing his education. He was in the University of Utah for two years, then completed work for the B.S. degree at the University of Chicago in 1905, and the M.A. degree at Columbia University in 1906. Nineteen years later he returned to the University of Chicago where, in 1925, he received with special honors the Ph.D. degree.

Besides his work in the mines, his experience included: teaching geology and mining in the Wu Han University, China, 1908–1909; instructor at the Pennsylvania State College, 1909–1911; in the New Mexico School of Mines, 1911–1917; and geologist for the American Smelting and Refining Company, 1917–1919. He was consulting geologist in Fort Worth, Texas, from 1919 until 1922 when he became professor of geology at the University of Oklahoma, which position he held until his recent death.

He was happily married to Lillian Cash, July 8, 1908, and they together maintained a delightful home in which their three children were born. Robert, the eldest, is a lawyer in Oklahoma City; Evelyn, the older of the two daughters, is the wife of D. W. Hogan, Jr., a banker in Oklahoma City; and Helen is continuing graduate work at Stanford University, California.

The immigrant boy soon caught the spirit of American freedom and began to capitalize on its opportunities. His patient perseverance, and willingness to work and sacrifice to secure a thorough education provided the experience requisite to advancement in his chosen field of geology. He thus became eligible to the leading geological organizations of the country. He was elected a member of the American Association of Petroleum Geologists in 1924 and Fellow of the Geological Society of America in 1933. He was a member of the Episcopal Church and a thirty-second degree Mason.

He did some consulting work in connection with his teaching, and he worked out the general structure and directed drilling of the early productive wells in the Oklahoma City oil field.

His thorough training and broad experience fitted him to teach a wide range of subjects. He had been working for several years on a book on sedimentation on which part of the proof had been read at the time of his death. William Ham, an instructor in the University, has been requested to finish the work on this book.

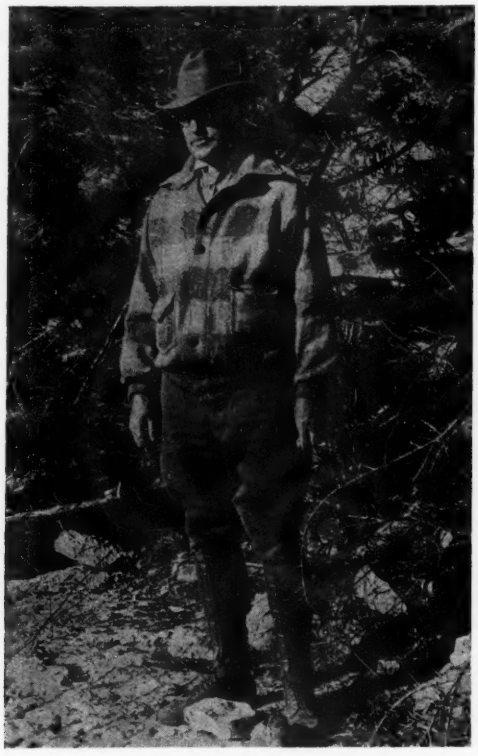
Dr. Anderson was respected by faculty, students, and fellow-townsmen. His genial smile and the many unobtrusive ways in which he rendered service to all about him are greatly missed.

CHARLES E. DECKER

THE UNIVERSITY OF OKLAHOMA
Norman, Oklahoma
September 19, 1940

JOSHUA WILLIAM BEEDE
(1871–1940)

Professor Joshua William Beede died at his home in Tulsa, Oklahoma, Tuesday, February 27, from shock resulting from a fracture of the thigh bone. Professor Beede had been in poor health for some time. He is survived



JOSHUA WILLIAM BEEDE

by his wife, Mrs. Clara McKee Beede and four daughters, Genevieve (Mrs. G. G. Henderson), Lydia May (Mrs. L. O. Todd), Lucile Prosser Beede, and Clara Frances Beede.

Professor Joshua William Beede was born at Raymond, New Hampshire, September 14, 1871, son of Hiram Pratt and Lydia Marie (Brown) Beede. During his early boyhood the family moved to Kansas to make a home on the wide "Prairie" which Dr. Beede so greatly loved throughout his life. He attended the local schools and Washburn College, at Topeka, graduating with

the B.S. degree in 1896. He received the Ph.D. degree from the University of Kansas in 1899, studying under the distinguished paleontologist, S. W. Williston. Also at Washburn College he came under the inspiring influence of Professor C. S. Prosser, at that time at Washburn, and later at Union College, Schenectady, New York, and still later head of the department of geology at Ohio State University. Dr. Prosser had the determining influence on Professor Beede's career. Through him Dr. Beede became interested in the Pennsylvanian and Permian rocks of Kansas, Oklahoma, and Texas, and made the study of these rocks and their fossils his life work. Dr. Beede was assistant in paleontology at the University of Kansas 1897–99, and teacher of science at the Atchison County High School, Effingham, Kansas, 1899–1901. In 1901 he was appointed instructor in geology at Indiana University, assistant professor in 1906, and associate professor in 1909. He served in the latter capacity till 1917, when he accepted a position as geologist with the Bureau of Economic Geology and Technology of the State of Texas. Professor Beede was to have succeeded Dr. J. A. Udden as State geologist, but resigned in 1922 to become geologist of the Empire Gas and Fuel Company. During his connection with the Texas Survey and the Empire company he published numerous additional papers on the geology and paleontology of the upper Paleozoic formations of Texas, including several that have become classics in this field. In 1928 he was invited to return to Indiana University in a temporary capacity as professor of geology during Professor Cumings' incumbency of the Waterman Research Professorship. This connection lasted till 1931. A few years later, his health and especially his eye-sight having failed considerably, he and Mrs. Beede returned to Oklahoma in order to be near their daughters. Professor Beede was a member of the Geological Survey of Kansas in 1896, 1898–99, and 1903–10; of the Oklahoma Survey in 1911–17; and of the United States Geological Survey in 1901–02.

Dr. Beede was one of that small group of pioneers—Cragin, Haworth, Prosser, Girty, Gould—who in the last decade of the 19th century began the detailed study of the upper Paleozoic rocks of Kansas and adjacent states; and demonstrated the presence of the Permian system in America. Dr. Beede's studies, especially, fixed the lower boundary of this important succession of rocks, and determined the faunal succession and the remarkable evolutionary changes that swept over the faunas of these late Paleozoic times. He accumulated extensive collections of fossils, now housed mostly in the museums of the universities of Kansas and Texas. He was an assiduous and tireless collector. His detailed knowledge of the geological formations of the Mid-Continent region was the envy and despair of the younger geologists; and his name was a household word in Kansas and Texas geology.

Besides his many important papers on the upper Paleozoic formations of Kansas, Oklahoma, and Texas, Professor Beede published several papers on Indiana geology, including one on the cycle of subterranean drainage, which was the first statement anywhere of this important drainage phenomenon, and also of the phenomenon of underground stream piracy, so well illustrated in this region.

Professor Beede was a Fellow of the Geological Society of America; and a member of the Paleontological Society; the Society of Economic Paleontologists and Mineralogists; the American Association for the Advancement of Science; the American Association of Petroleum Geologists; the Indiana

Academy of Science; and of the Kansas Academy of Science; Phi Beta Kappa; Sigma Gamma Epsilon; and Sigma Xi. He was one of the founding members of the Indiana chapter of the latter society.

Dr. Beede was a man of extreme modesty and unbounded generosity. So long as he was able to help others no one ever asked him for help in vain—whether it was for financial assistance, or for advise and comfort in stress and adversity. Though his manner and methods in teaching were somewhat difficult to follow, he was greatly beloved by his students because of his sympathetic helpfulness and his vast enthusiasm for scientific research. He was at his best in the field, in the out-of-doors, in his tireless investigation of the rocks and their fossils at first hand. His life and his work will not be forgotten.

E. R. CUMINGS

INDIANA UNIVERSITY
Bloomington, Indiana
March, 1940

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The seventeenth annual fall meeting of the Pacific Section of the Association will be held at the Ambassador Hotel, Los Angeles, California, November 7 and 8. The president of the section is ALBERT GREGERSEN, The Texas Company, and the secretary-treasurer is E. J. BARTOSH, Bankline Oil Company.

RUSSELL R. SIMONSON is geologist with the Union Oil Company of California. His address is 211 Philippine Street, Taft.

W. E. HEATER has changed his address from Los Angeles to 1040 Ardmore Avenue, Oakland, California.

WILLIAM W. RAND has moved from Ventura, California, to 1706 Dearing Place, Tuscaloosa, Alabama.

ROBERT CECIL LANE, formerly with Godfrey L. Cabot, Inc., is an independent geologist, Lake Waco Drive, Waco, Texas.

E. G. ALLEN, one of the original members of the Association, has moved from Laguna Beach, California, to 4601 Park Lane, Dallas, Texas.

R. B. MORAN, JR., is in the employ of the Superior Oil Company at Bakersfield, California.

J. H. DEMING, formerly with The Texas Company at Cairo, Egypt, is now at the company office in Houston, Texas.

C. WILLIAM SAVILLE, formerly with the Colombian Petroleum Company at Cucuta, is with The Texas Company, Apartado Postal 877, Bogotá, Colombia.

JOHN S. HEROLD has left the Shell Oil Company, Inc., at Midland, and is with the Sun Oil Company, Box 2880, Dallas, Texas.

RALPH G. HUBMAN has moved from Boulder, Colorado, and may be addressed in care of The Texas Company at Wheeling, West Virginia.

SHERRIL A. SHANNON, of the Cities Service Oil Company, has been transferred from Wichita to Great Bend, Kansas.

HOWARD E. ROTHROCK, who is in charge of the geological work of the CCC in State parks, national parks, and national monuments, temporarily has assumed the duties of the chief of the naturalist division, National Park Service, due to the resignation of EARL A. TRAGER. Trager has accepted a position with the Bell and Howell Company, manufacturers of motion-picture equipment.

PAUL A. WHITNEY is district manager for the General Geophysical Company in charge of seismograph, core drilling, and slim-hole rotary drilling in the northern Mid-Continent. His address is Box 187, Mt. Vernon, Illinois.

R. W. MALLORY is geologist for the Stanolind Oil and Gas Company at Casper, Wyoming.

JOHN VAN NOSTRAND, of the United States Geological Survey, has returned from Colorado. His address is 1511 Twenty-Second Street, N. W., Washington, D. C.

CLAUDE N. VALERIUS, of the Barnsdall Oil Company, has been transferred from El Dorado, Arkansas, to Wichita Falls, Texas.

GEORGE B. SOMERS has changed his address from the Socony-Vacuum Oil Company, Cairo, Egypt, to 721 Browder Street, Dallas, Texas.

WARD C. BEAN is with the Shell Oil Company, Inc., at Wichita Falls, Texas.

JOHN H. LOCK, of the Sinclair Prairie Oil Company, has moved from Corpus Christi to Tyler, Texas.

P. A. MEYERS, of the Pan American Production Company, has moved from Corpus Christi, to Houston, Texas.

EMIL OTT, consulting geologist, of San Angelo, W. W. GRUBER and R. P. LYNN, of San Antonio, Texas, have organized the Three Widows Oil Company.

MARSHALL W. MYERS, production engineer of the Phillips Petroleum Company, Bartlesville, Oklahoma, has enlisted in the United States Army as a second lieutenant.

WILLIAM A. RICE, Ph.D. Yale, 1940, and recently teacher of general mineralogy and economic geology at the Utah State Agricultural College, has been employed as a trainee in the exploration department of the Shell Oil Company, Inc., Tulsa, Oklahoma.

LEO F. HUNT, B.Sc. Nebraska, 1939, has been employed by the Stanolind Oil and Gas Company, Tulsa, for field work in Kansas.

MALCOLM D. BENNETT, JR., of the Continental Oil Company, has moved from Jackson, Mississippi, to 2142 Bolsover Road, Houston, Texas.

JAMES C. MCCULLOCH, of the Carter Oil Company, has moved from Saginaw, Michigan, to Mattoon, Illinois.

SERGE M. PERTUSIO is in the geological department of the Columbian Carbon Company, 41 East 42d Street, New York City.

HERBERT HOOVER, JR., president of the United Geophysical Company, Pasadena, California, returned in September from a month's trip in South America, visiting company operations in Brazil and Argentina.

Lieutenant ROBERT C. REDFIELD may be addressed at Kemper Military Institute, Boonville, Missouri.

LEWIS C. CRIDER has returned from Karachi, India, where he was employed by the Indian Oil Concessions, Ltd., and is at 1907 Fifteenth Street, Lubbock, Texas.

L. KEHRER has left the Caribbean Petroleum Company at Maracaibo Venezuela, and is with the Shell Company of Ecuador, Ltd., Palacio del Comercio, Apartado 340, Quito, Ecuador, S. A.

JOHN M. SCROGIN has moved from Jackson, Mississippi, to Rosenberg Texas.

JULIAN K. PAWLEY is with the General Geophysical Company, Box 294. Wooster, Ohio.

CYRIL K. MORESI resigned as Louisiana State geologist, effective September 1, and has opened a consulting office at 617 Carondelet Building, New Orleans, Louisiana. Moresi was in charge of the geological division of the State Conservation Department since 1931, during which time eighteen geological bulletins and several other technical reports were published.

HARVEY J. SIMMONS, JR., of Godfrey L. Cabot, Inc., is located at Charleston, West Virginia.

W. A. REITER, of the Fohs Oil Company, talked before the Houston Geological Society, at its first fall meeting, on the subject, "Recent Research on the Origin of Petroleum."

EDWARD MARTIN KINDLE, chief of the division of paleontology of the Canadian Geological Survey since 1912, died recently in Ottawa, at the age of 71 years.

S. D. BUTCHER has moved from Shawnee, Oklahoma, to 4 Lakeside Boulevard, Eastborough, Wichita, Kansas.

FRANK E. LOZO, JR., who has been with the Gulf Oil Corporation at Midland, Texas, may be addressed in care of the department of biology and geology at Texas Christian University, Fort Worth, Texas.

RICHARD HUGHES, petroleum geologist of Tulsa, has returned from Grand Rapids, Michigan, and may be addressed at 2139 East 29th Street, Tulsa, Oklahoma.

JOHN F. BARNETT, JR., formerly with the Standard Oil Company of Venezuela at Caracas, is now with the West India Oil Company, S. A., Apartado 367, Azua, Republica Dominica.

GEORGE DICKINSON, formerly with the Venezuelan Oil Concessions, Ltd., is now with the Caribbean Petroleum Company, Maracaibo, Estado Zulia, Venezuela.

A. E. BRAINERD, geologist with the Continental Oil Company, Denver, Colorado, headed a field trip of the Panhandle Geological Society in southeastern Colorado, September 21 and 22.

D. B. WINFREY, of the Petty Geophysical Engineering Company, has been transferred from Yazoo City, Mississippi, to Beeville, Texas.

MARTIN J. DEUTH, of the Shell Oil Company, Inc., is now at Paducah, Texas.

HARRY H. NOWLAN has resigned from the Darby Petroleum Corporation, San Antonio, Texas, and is connected with the North Central Oil Corporation of 317 Court Building, Evansville, Indiana, and 120 Broadway, New York City. His headquarters office is in Evansville.

WILLIAM W. PORTER II, consulting geologist, 244 South Gramercy Place, Los Angeles, California, has returned from a consulting engagement in the Philippines and a brief visit to China and Japan.

H. B. FIELDS may be addressed at Vetramar S.A.P.A., Casilla de Correo 18, San Pedro de Jujuy, Argentina.

NOEL R. PARK has returned from Cairo, Egypt, and may be addressed at Box 1249, Houston, Texas.

The Petroleum Division of the American Institute of Mining and Metallurgical Engineers meets in Los Angeles, October 17 and 18, and in Tulsa, October 24, 25, and 26.

The Illinois Geological Survey of the State Department of Registration and Education, the Engineering Experiment Station of the University of Illinois, and the Illinois Mineral Industries Committee extend a most cordial invitation to all the mineral industries of Illinois and her sister states, and to all allied organizations, to join them in holding a mineral industries conference and in helping them to dedicate the new Natural Resources Building, at the University of Illinois in Urbana-Champaign, on Thursday and Friday, November 14 and 15.

J. HUNER, JR., formerly assistant State geologist of the Louisiana Geological Survey, has been appointed to the position of State geologist to succeed CYRIL K. MORESI. Plans of the Louisiana Geological Survey call for an increased personnel in order to initiate a detailed investigation of producing areas in Louisiana. The following district geologists have been appointed: J. L. MARTIN, northwest Louisiana; P. M. LYONS, northeast Louisiana; S. M. MCDONALD, southeast Louisiana, and T. E. LEROY, southwest Louisiana. It is also contemplated that four junior geologists will be appointed for the purpose of collecting well samples, electrical logs, and other necessary drilling data.

The Indiana-Kentucky Geological Society held its first autumn meeting at Evansville, Indiana, September 20, and elected the following officers for the coming year: president, E. W. HARD, Sun Oil Company; vice-president, PERRY MCCLURE, Shell Oil Company; secretary-treasurer, STANLEY G. ELDER, Sun Oil Company, all of Evansville, Indiana; and as members of the executive committee, R. R. MUNOZ, Terrace Oil Company, Evansville, Indiana, and J. A. BROWN, Kentucky Natural Gas Company, Owensboro, Kentucky.

HELEN TAPPAN LOEBLICH is in the department of geology at Tulane University of Louisiana, New Orleans.

HARRY KILIAN is with the Union Sulphur Company, Inc., Sulphur Mines, Louisiana.

J. B. NANCE, formerly at Houston, Texas, may be addressed in care of the

Maryland and Pennsylvania Railroad Company, 135 West North Avenue, Baltimore, Maryland.

At the first fall meeting of the Ardmore Geological Society, October 1, at Ardmore, Oklahoma, Baroid well-logging equipment will be explained. Secretary TOM L. COLEMAN, Box 719, Ardmore, announces the following list of bulletins of previous field trips of the Society are still available at 25 cents each, plus postage: (1) Study of Lower Pennsylvanian, Mississippian, and Ordovician formations of North and West side of Llano Uplift; (2) Hoxbar and Deese South of Ardmore; (3) Structure of Criner Hills; (4) Trip from Ardmore to Ouachita Mountains; (5) Lower Pennsylvanian in Berwyn and Baum Areas; (6) Study of Pennsylvanian Outcrops in Palo Pinto, Parker, Eastland, Brown, and Coleman counties, Texas.

JOSEPH B. TEICHMAN, of the Atlantic Refining Company, has moved from Dallas to Midland, Texas, where he is employed in the company's geological laboratory in the Petroleum Building.

ROLF ENGLEMAN, recently at Warren, Ohio, is situated at 154 Albany Avenue, Shreveport, Louisiana.

WALTON SUMNER, of the Socony-Vacuum Oil Company, has moved from Aguas Claras, Santander, to Barranquilla.

LEROY T. PATTON, head of the department of geology and petroleum engineering, Texas Technological College, Lubbock, Texas, announces the appointment of CLIFFORD HORN, formerly research associate in the department of petroleum and natural gas engineering at the State College of Pennsylvania, to the position of instructor in petroleum production engineering.

T. P. WOODWARD, since completing a sand and gravel survey of Louisiana for the Louisiana State Geological Survey, has been working in the area of the Loudon pool, Illinois, for the Carter Oil Company, as a geological trainee for the Standard Oil Company of Venezuela.

RALPH EVANS, formerly in the employ of the Ramsey Petroleum Corporation at Oklahoma City, and the Cities Service Oil Company at Bartlesville, was granted the B.S. degree in geology at the University of Oklahoma, June, 1940. His present address is Hugo, Oklahoma.

RAY A. WALTERS, formerly with the Standard Oil Company of Louisiana at Shreveport, Louisiana, is with the Carter Oil Company at Meridian, Mississippi.

ALLEN EHLERS, of the Carter Oil Company, has moved from Warren, Ohio, to Saginaw, Michigan.

L. DAVID WOSK, consulting geologist, is situated at 1009 Subway Terminal Building, Los Angeles, California.

MURRAY J. WELLS, of the Indian Territory Illuminating Oil Company, has moved from Oklahoma City to Bartlesville, Oklahoma.

RUSSELL H. DICKEN, recently at Morgan City, Louisiana, is located at Sinton, Texas.

JOHN C. MAXWELL, recently with the Sun Oil Company at Beaumont, Texas, may be addressed at the department of geology, Princeton University, Princeton, New Jersey.

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FIELD TRIPS

APPALACHIAN GEOLOGICAL SOCIETY, NOVEMBER 1–2

The Appalachian Geological Society will hold a dinner meeting in the Fort Hayes Hotel, Columbus, Ohio, at 6:30 P.M. on Friday, November 1. Guest speakers will be the State geologists of Ohio, West Virginia, Kentucky, Indiana, and Michigan. Tickets to the dinner will be $1.25. Instructors and students in geology are cordially invited.

On the following morning J. Ernest Carman, chairman of the department of geology at Ohio State University, will conduct a field trip in Rocky Fork near Gahanna, Ohio. Transportation will be in members' cars. Exposures from near the top of the Ohio shale up to the basal part of the Sunbury shale will be studied in a locality where the Berea sandstone is very similar in character to that in the producing areas to the east. The party will assemble at 8:30 A.M. on Saturday at the junction of Federal Route 62 and State Route 317 at Gahanna about 8 miles northeast of Columbus.

A block of seats will be reserved at $2.50 each for the Indiana-Ohio State football game in Ohio Stadium on Saturday afternoon.

Rates at the Fort Hayes Hotel range from $2.50, single, and $3.50, double. Those who plan to attend are asked to make their own hotel reservations and to make reservations for the dinner and football game by notifying J. R. Lockett, president of the Appalachian Geological Society, Ohio Fuel Gas Company, Columbus, Ohio. Reservation for the game must be made before October 15.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES, NOVEMBER 2–3

The fall field trip of the New Mexico Bureau of Mines and Mineral Resources will take place in Sierra and Socorro counties, New Mexico, on the first week-end in November. The party will assemble in Hot Springs on Friday evening, November 1, 1940.

On the first day, Saturday the 2nd, the leaders will show a complete section of the Pennsylvanian and the lower part of the Permian in the Mud Springs Mountains, near Hot Springs. In addition, time will be available to see some of the geology around Elephant Butte dam. On the second day, the entire Permian section will be shown near Socorro.

The leaders will be M. L. Thompson and C. E. Needham, School of Mines, Socorro, New Mexico. A log of the trip with considerable geologic information will be furnished free to those interested in making the trip.

Those expecting to spend the night of Friday, November 1, in Hot Springs, should communicate with the Hot Springs Chamber of Commerce regarding hotels and camps. Those expecting to spend the night of Saturday, November 2, in Socorro, should communicate with C. E. Needham, president, New Mexico, School of Mines, Socorro, New Mexico.

SOUTH TEXAS GEOLOGICAL SOCIETY ANNUAL MEETING, OCTOBER 18–19

The annual meeting of the South Texas Geological Society is being held in the auditorium of the School of Geology of the University of Texas, Austin, Texas, on Friday, October 18. Charles H. Row, chairman of the program committee, announces the following program.

1. HAL P. BYBEE, director, School of Geology, Austin: Welcome to the University of Texas

2. FRED P. SHAYES, president, South Texas Geological Society, Beeville: Response

3. FRITH C. OWENS, Corpus Christi: Highlights in Geological Developments in South Texas during 1940

4. ARNOLD ROMBERG, Houston: The Gravity Meter and Its Use

5. C. D. LOCKWOOD, Texas Oil Report, Houston: Petroleum and the War Situation

6. M. C. BOWSKY, Lane-Wells Company: New Determinations from Electrical Logs

7. Business meeting

8. GRADUATE STUDENTS, University of Texas, introduced by Hal P. Bybee, Austin: Our Field Problems

9. H. B. STENZEL, Bureau of Economic Geology, Austin: Relationships of the Carrizo Sand

10. R. H. ROBIE, Shell Oil Company, Inc., San Antonio: The Wilcox in South Texas. Followed by W. H. CURRY, R. N. KOLM, E. C. RACH, and others on specific Wilcox developments in South Texas

11. R. H. CUYLER, University of Texas, Austin: Facts about Our Field Trip

12. E. H. SELLARDS, director, and assistants, Bureau of Economic Geology, Austin: Conducted Tour of Memorial Museum

On the evening of the 18th there is an informal dinner in the ball room of the Student Union Building, followed by a smoker and conducted tours of the laboratories of the Geology Building.

On Saturday, October 19, a field trip is scheduled at 8:00 o'clock to cover the route through Elgin, Bastrop, and on to Smithville, to study the Wilcox and part of the Claiborne section. The field trip party disbands at Smithville about 5:00 P.M.

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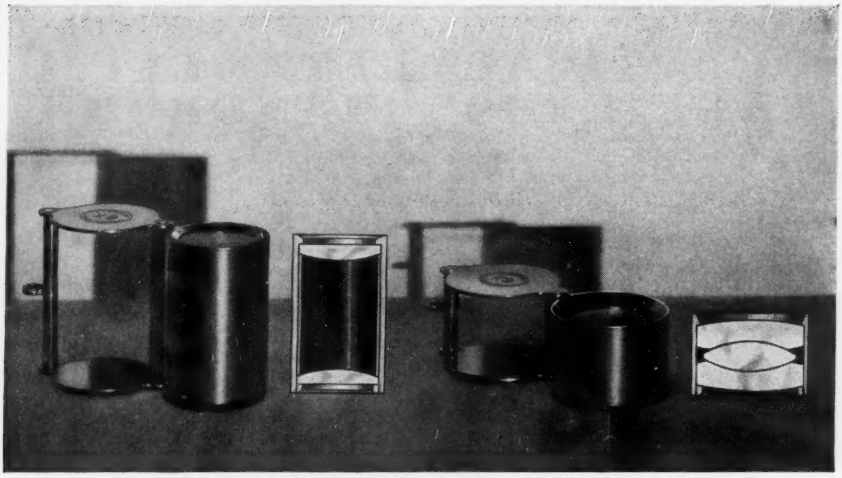

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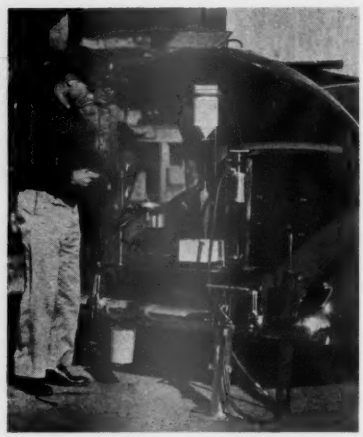

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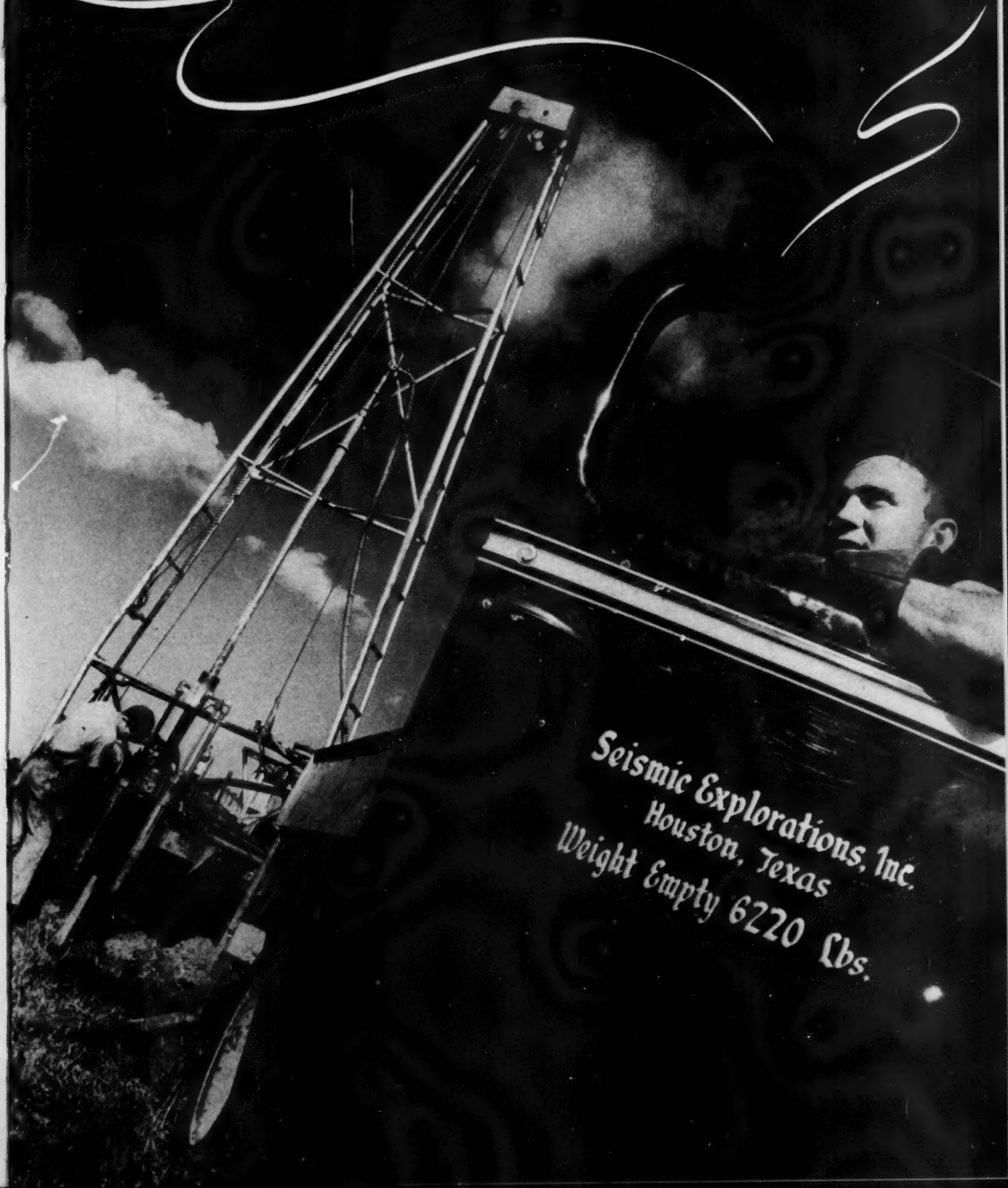

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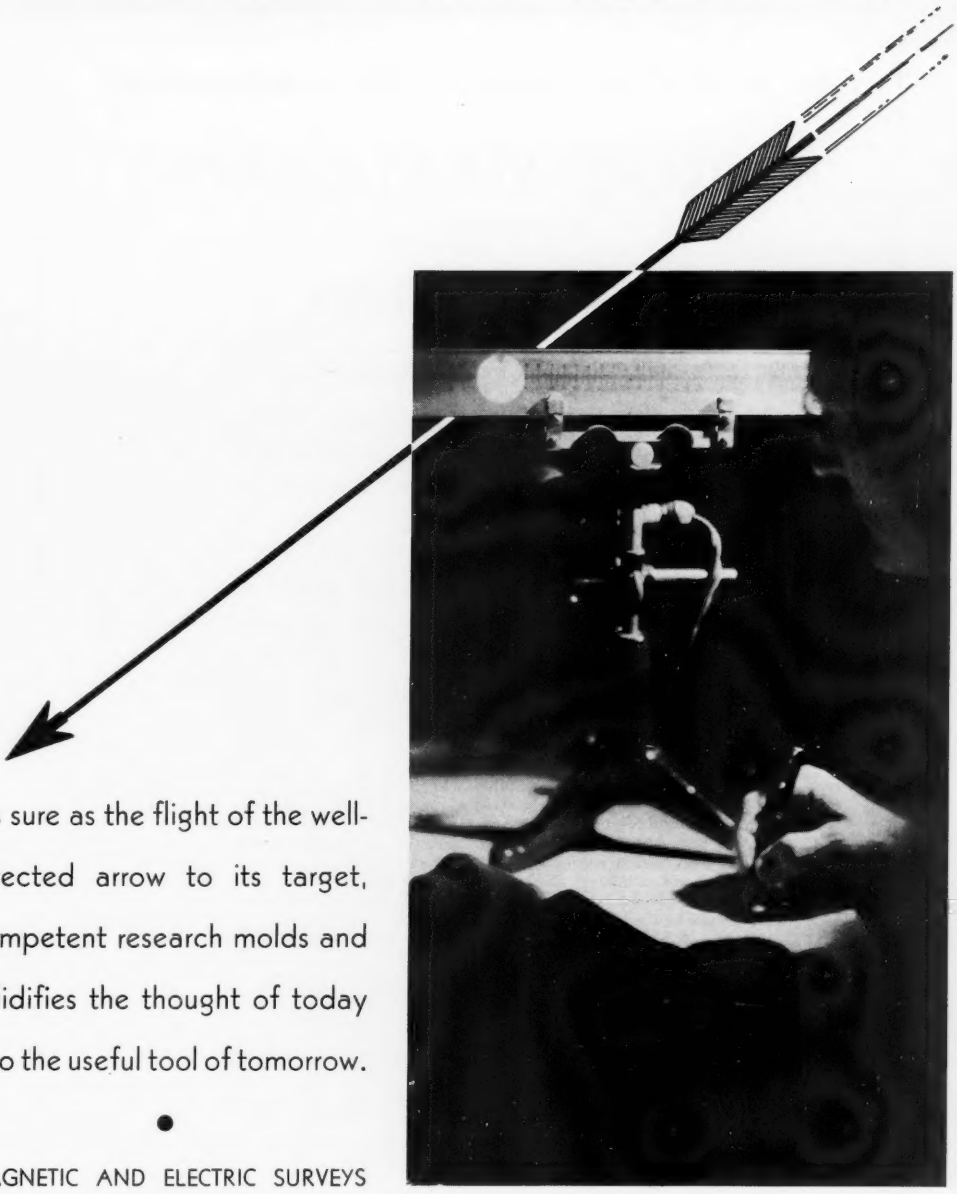

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(From page 2)

MIOCENE STRATIGRAPHY OF CALIFORNIA

Fig. 2.—Outline sketch of California, showing locations of some important Miocene foraminiferal sections with relation to approximate distribution of marine Neogene.

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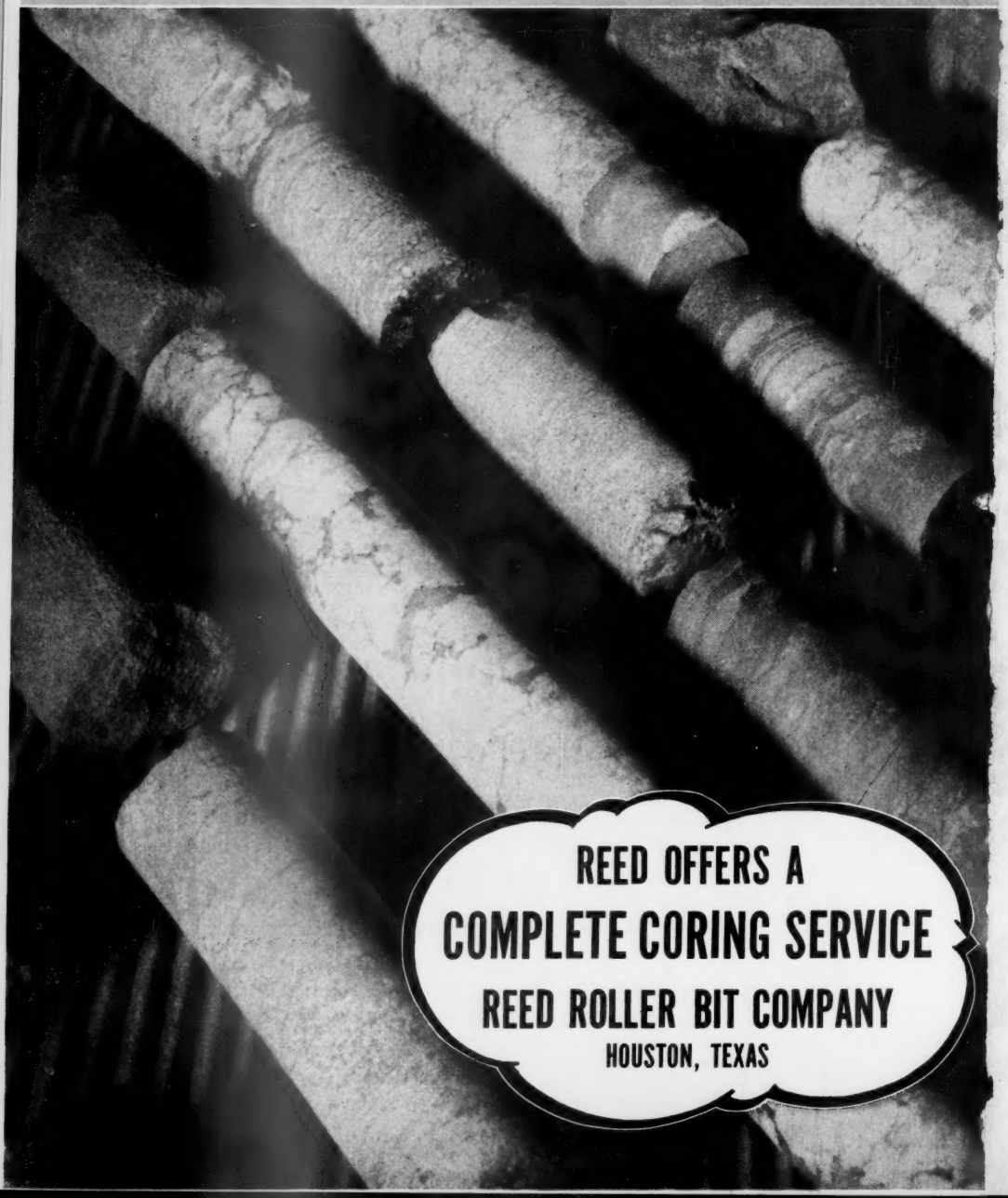

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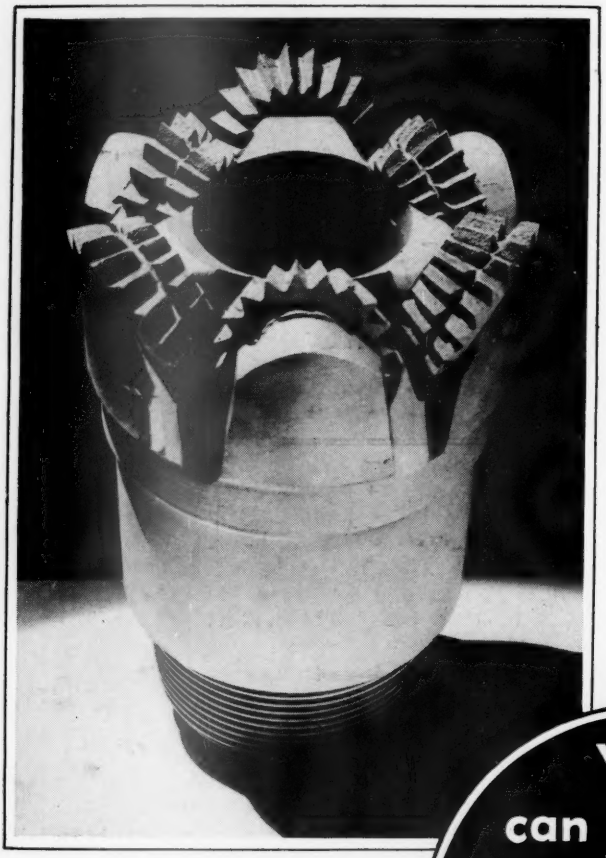

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